Shape and Ergonomics: Methods for Analyzing Shape and Geometric Parameters of Agricultural Parcels

T. Machl[1], A. Donaubauer[1], H. Auernhammer[2] and T. H. Kolbe[1]

[1] Technische Universität München, Chair of Geoinformatics,
Arcisstraße 21, D-80333 München,
{thomas.machl, andreas.donaubauer, thomas.kolbe}@tum.de

[2] Technische Universität München, Chair of Agricultural Systems Engineering,
Am Staudengarten 2, D-85354 Freising-Weihenstephan,
hermann.auernhammer@wzw.tum.de

ABSTRACT

Shape and further geometric characteristics of agricultural parcels are main factors with respect to machinability, working time requirement, and arising costs for cultivating agricultural acreages. Due to missing comprehensive statistical information on existing agricultural field structures regarding shape and ergonomically relevant geometric properties, most ergonomic simulations are based on simplified assumptions and therefore admit only limited information about real conditions. In this context this research project focuses on the development of methods for a comprehensive classification, characterization, and statistical description of ergonomically relevant geometrical properties of existing agricultural parcels on a large scale. Results gained provide basic information for continuative research in the fields of ergonomic simulations and agricultural engineering.

Keywords: Parcel geometry; agricultural parcel; ergonomics; geoinformatics; GIS; shape analysis; Germany

1. INTRODUCTION

Besides properties of agricultural parcels like relief and soil type, especially geometric properties like shape and size are main factors having a strong impact on machinability, working time requirement, and arising costs for cultivating agricultural acreages.

So far, different studies focused on the description of structural differences regarding the size of agricultural parcels as one factor having impact on machining properties (Bökel, 1999; Zenger, 2011). Just as important as size are further geometric characteristics like shape and geometric parameters of an agricultural parcel.

From an ergonomic point of view, simple geometric shapes like elongated rectangles, squares and trapezia are considered to be well suited for the use of agricultural machinery (Mauersberger, 1994; Schnurrbusch, 1991). Furthermore, even at the same shape, geometric characteristics like length and width have clear influence on machining prop-

T. Machl, A. Donaubauer, H. Auernhammer and T. H. Kolbe. “Shape and Ergonomics: Methods for Analyzing Shape and Geometric Parameters of Agricultural Parcels”. EFITA-WCCA-CIGR Conference “Sustainable Agriculture through ICT Innovation”, Torino, Italy, 24-27 June 2013. The authors are solely responsible for the content of this technical presentation. The technical presentation does not necessarily reflect the official position of the Internation Commission of Agricultural and Biosystems Engineering (CIGR) and of the EFITA association, and its printing and distribution does not constitute an endorsement of views which may be expressed. Technical presentations are not subject to the formal peer review process by CIGR editorial committees; therefore, they are not to be presented as refereed publications.

erties. Particularly rectangles with a ratio of length:width of 2:1 (Diemann, 2001) or 2:1 to 5:1 (Liste, 1992) are considered to be very favorable.
Due to missing comprehensive statistical information regarding regional distributions of different shape types as well as ergonomically relevant geometric properties of agricultural parcels, most ergonomic simulations on the effects of the geometry of agricultural parcels are based on highly simplified assumptions. For that reason, the results of those simulations provide only limited information about real conditions.
Against this background, this research focuses on the development of methods for a comprehensive classification, characterization, and statistical description of the geometry of existing agricultural parcels on a large scale.

2. MATERIALS AND METHODS

Based on an object oriented conceptual data model with an appropriate implementation in an object-relational Open Source geodatabase system an indicator-based multilevel classification algorithm was developed for categorizing shape and characterizing ergonomically relevant geometric properties of agricultural parcels.

2.1 Input Data

The methods for the comprehensive description of shape and ergonomically relevant geometric characteristics of agricultural parcels are based on geospatial data from the Land Parcel Identification System (LPIS) as a fundamental part of the Integrated Administration and Control System (IACS). This system is an essential element of the technical implementation of the Common Agricultural Policy stipulated in the early 1990s. LPIS is legally defined in Regulations (EC) No. 1593/2000 and No. 1782/2003. Since 2005 all member states of the European Union are obliged to introduce and implement an “identification system for agricultural parcels” making use of “computerized geographical information system techniques“. As a result geospatial data on agricultural reference parcels are available for most of the EU member states.
As test-instances for the development and validation of the approach all farmer’s block objects within the Bavarian administrative unit Schwaben were used. The test-instance provides geospatial information about approximately 265,000 agricultural parcel objects (farmer’s block) of 19,000 farmers registered in Schwaben and covers more than 530,000 hectares of agricultural land. Besides distinct grassland-regions also areas where arable farming predominates can be found.

2.2 Methods for Quantification of Shape

In literature indicators are frequently used for the description of shape. Especially in the field of digital image processing such indicators are very common (Sarfraz *et al.*, 2007). For the description of agricultural parcels from an ergonomic point of view particularly convexity, rectangularity, isoperimetric quotient and triangularity are relevant indicators. All indicators are within a value range from 0 (strong deviation) to 1 (no deviation) and are defined as follows:

- *Convexity*
  Convexity is an important indicator describing an essential characteristic of the shape of a polygon. Commonly the convexity describes the deviation of a polygon from its convex hull polygon. In this study an approach described by Oksanen (2007) and Zunic (2004) is applied for the quantification of convexity: the ratio of the area of a polygon (A_{poly}) and the area of its convex hull polygon (A_{ch}). Convexity is defined as:

$$convexity = \frac{A_{poly}}{A_{ch}}$$

- *Rectangularity*
  In literature rectangularity of a polygon is mostly quantified using the ratio of the area of a polygon and the area of its minimum bounding rectangle (mbr) whereby the mbr is minimized by area (Oksanen, 2007; Rosin, 2003).
  This approach is adopted and further developed. In this study rectangularity is quantified using the ratio of the area of a polygon's convex hull polygon (A_{ch}) and the area of the polygon's mbr (A_{mbr_a}). This step makes it possible to distinguish different reasons for an areal deviation of a polygon from its mbr: deviation caused by concavity of a polygon and a deviation of the polygon's convex hull from its mbr.

$$rectangularity_{a\_ch} = \frac{A_{ch}}{A_{mbr\_a}}$$

  Furthermore, rectangularity of a polygon's convex hull polygon (A_{ch}) is also quantified regarding the mbr minimized subject to width (A_{mbr_w}) as:

$$rectangularity_{w\_ch} = \frac{A_{ch}}{A_{mbr\_w}}$$

- *Isoperimetric quotient*
  The isoperimetric quotient (IQ) and derived indicators are frequently used as indicators describing compactness of a polygon (Montero *et al.*, 2009; Peura *et al.*, 1997). A_{poly} stands for the area and P_{poly} for the perimeter of a polygon.

$$IQ = \frac{4 * \pi * A_{poly}}{{P_{poly}}^2}$$

- *Triangularity*
  O'Rourke *et al.* (1986) describe an algorithm for the determination of the minimum bounding triangle of a polygon. Rosin (2003) adopts this algorithm and developed an indicator describing triangularity similar to rectangularity. Due to the enormous computation effort, this approach is not applicable on a large scale and therefore not used in this research project.

2.3 Data Mining and Data Processing

Key element for the analysis of the shape and ergonomically relevant characteristics of existing agricultural parcels is an object oriented conceptual data model with an appropriate implementation in an object-relational Open Source geodatabase system (PostgreSQL/PostGIS). On this basis analysis-tools are developed using the software packages R, ArcGIS 10.1 and QuantumGIS (figure 1). While ArcGIS and QuantumGIS extend functionalities of PostGIS concerning processing and the visualization of geospatial data, R especially in combination with PostgreSQL/PostGIS – allows for a powerful, efficient and automated preparation, analysis and statistical description of large amounts of data.

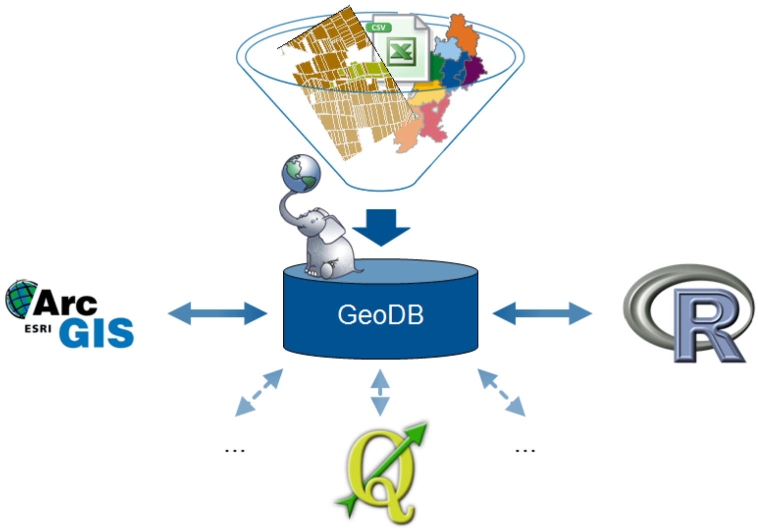


Figure 1. System architecture

2.4 Shape Classification

After importing the geospatial data into the database and computing the indicators described above, the shape of agricultural parcels is classified using a multilevel classification algorithm. Core elements of this classification algorithm are indicator thresholds, which are the result of a visual calibration process.
In a first stage ‘concave polygons’ and ‘circular polygons’ are classified using thresholds for indicators directly referring to the agricultural parcel polygon. In the subsequent stages field parcel polygons are first differentiated according to their degree of convexity before the shape is classified in an indirect procedure based on indicators referring to the convex hull of a polygon as ‘square’, ‘rectangle’, ‘polygon with high rectangularity’, triangle’ and ‘others’ (figure 2).
Due to the enormous computation effort for the determination of minimum bounding triangles (see 2.2) for the identification of triangles a new approach is taken using the indicator $rectangularity_{w\_ch}$ making use of two fundamental principles: firstly, for a tri-

angle the smallest width of a mbr minimized by width equals the smallest height of a triangle. Secondly the area of a triangle is half the area of the rectangle defined by base and perpendicular height, which is in this case the mbr minimized subject to width.
Beyond information regarding the shape, ergonomically relevant parameters like length, width, and further characteristics are calculated and used for semantic enrichment of the parcel object within the database. This approach allows on the one hand to carry out statistical analyses on different levels of aggregation and with high performance. On the other hand all relevant information gained is available for further complex investigations in ergonomics, economics, ecology or agricultural engineering.

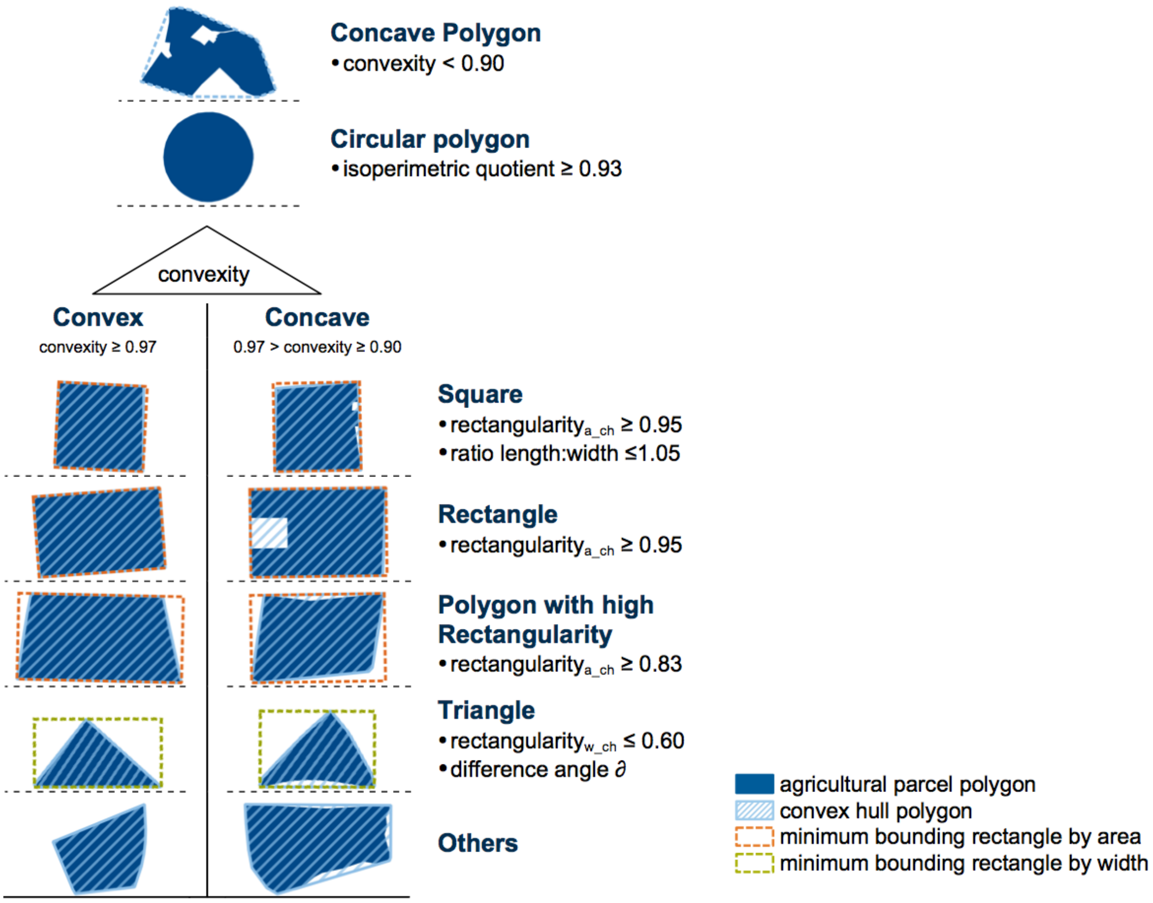


Figure 2. Multilevel indicator-based shape classification algorithm

3. RESULTS

By the developed methods and procedures, it is now possible to perform a comprehensive description, classification and characterization of geometric properties of existing agricultural parcels on a large scale. Figure 3 shows the results of the classification algorithm for a section of the investigated area.

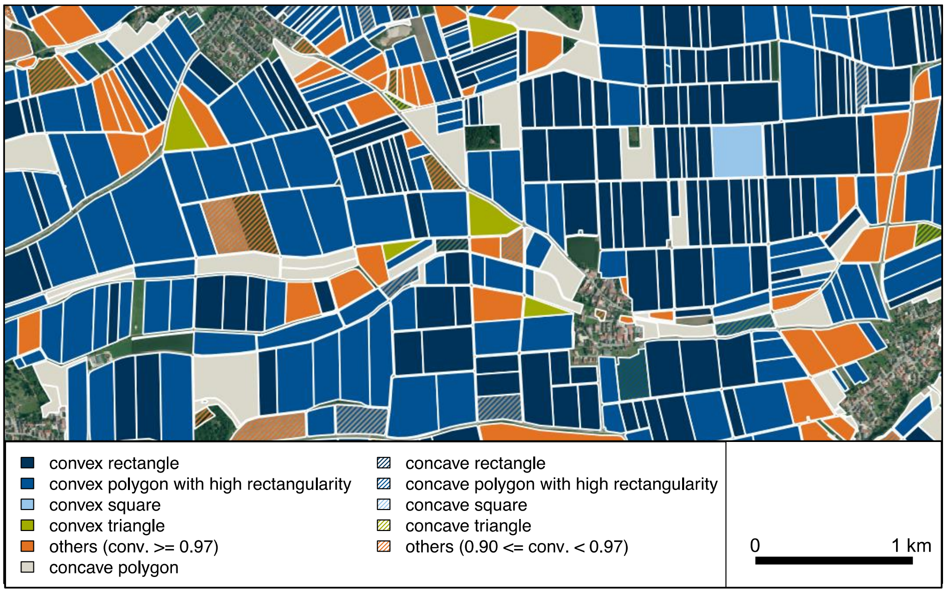
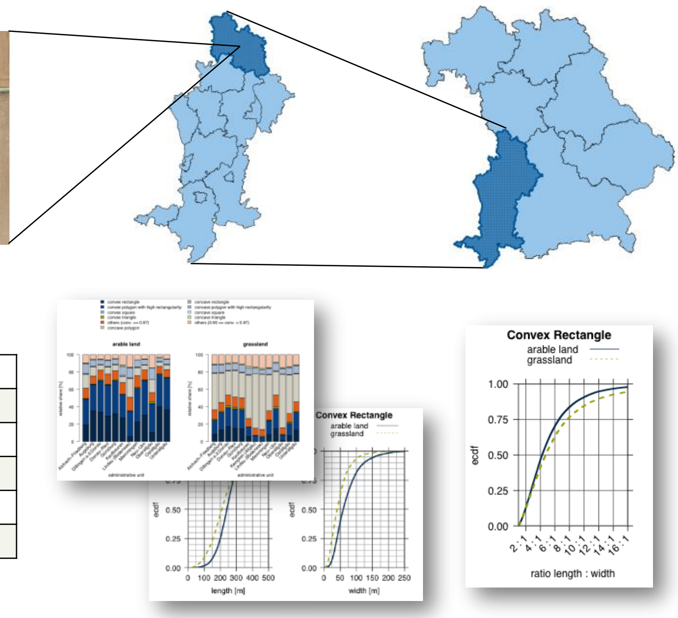


Figure 3. Exemplary results of the developed multilevel shape classification algorithm

Due to semantic enrichment of objects within the database all information on shape and ergonomically relevant characteristics of the parcel objects are available for various subsequent statistical analyses and ergonomic simulations at different levels of aggregation. Depending on the objective, this level might be a single agricultural parcel, a farm, an administrative unit or any other relevant statistical unit (figure 4).



...	...
shape	convex rectangle
length	270 m
width	159 m
lwr	1.7:1
...	...

... ...

Figure 4. Exemplary statistical description of results gained at different levels of aggregation (single agricultural parcel, administrative district and region)

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T. Machl, A. Donaubauer, H. Auernhammer and T. H. Kolbe. “Shape and Ergonomics: Methods for Analyzing Shape and Geometric Parameters of Agricultural Parcels”. EFITA-WCCA-CIGR Conference “Sustainable Agriculture through ICT Innovation”, Torino, Italy, 24-27 June 2013.

At the aggregation level of the Bavarian administrative unit Schwaben about 75 % of all arable parcels and nearly 40 % of all machined grassland parcel objects could be classified using simple geometries like rectangles, polygons with high rectangularity, triangles or squares.
However, there are clear regional differences in structural conditions for the use of machines both in terms of regionally varying proportions of different shape types as well as with respect to ergonomically relevant geometric characteristics of agricultural parcels. Furthermore, there are clear differences between arable land and grassland which means for grassland a significant higher proportion of concave polygons and a much lower share of rectangles and polygons with high rectangularity compared to parcels with arable use.

4. CONCLUSIONS AND OUTLOOK

The presented multilevel indicator-based classification algorithm makes it possible to conduct comprehensive classification and characterization of ergonomically relevant geometric properties of existing agricultural parcels at the level of a single agricultural parcel. For this application geospatial data from the Land Parcel Identification System provide a solid basis due to the high data quality regarding positional, temporal and thematic accuracy as well as completeness.
The gained information regarding the geometric characteristics of agricultural parcels is used for the semantic enrichment of the parcel objects within the database and is therefor available for ergonomic simulations and further investigations in the fields of ergonomics, economics, ecology or agricultural engineering.
The developed procedures and methods are designed to be applicable on a large scale. Consequently, in a next step the study area will be extended to the entire area of Bavaria. Furthermore three-dimensional properties of agricultural parcels will be taken into account. This means on the one hand the originally two-dimensional LPIS data have to be draped over a digital terrain model with appropriate quality characteristics. On the other hand suitable morphometric indicators for the description of three-dimensional properties of agricultural parcels have to be found and suitable methods for calculating the indicator values have to be developed. The core conceptual schema must be extended to cope with the requirements defined by the morphometric indicators and the three-dimensional data.
Other major challenges are the modeling of the temporal evolution of agricultural parcel objects under consideration of topological relations to the surrounding objects.

5. REFERENCES

BÖKEL, M. 1999. Analyse und regionale Zuordnung der Schlaggrößen in Bayern. Diploma thesis. Freising-Weihenstephan: Technische Universität München.

Diemann, R. 2001. Expertengespräch zur 21. DLKG-Tagung: "Schlagstruktur und Schlaggröße im Spannungsfeld gegensätzlicher Interessen". *Landnutzung und Landentwicklung* 42 (3): 138–139.

Dietzel, H.; R. Diemann, R. Jacobs and R. Otto. 2000: Schlaggröße und Schlagform in Ackerbaugebieten der neuen Bundesländer. *Zeitschrift für Kulturtechnik und Landentwicklung* (41): 1-6.

Liste, H. J. 1992. Schlaggruppen statt Riesenschläge. *Neue Landwirtschaft* (1): 35–37.

Machl, T. 2012. Indikatorbasierte Analyse von Feldstücksform und Feldstücksgeometrie auf Grundlage von InVeKoS-Daten. Freising-Weihenstephan: Technische Universität München.

Mauersberger, V. 1994. Neue Schlaggestaltung - Erfordernisse und Möglichkeiten. *Neue Landwirtschaft* (8): 44–45.

Montero, R. S. and E. Bribiesca. 2009. State of the art of compactnesss and circularity measures. *International Mathematical Forum* (4): 1305–1335.

Oksanen, T. 2007. Path planning algorithms for agricultural field machines. Ph.D. diss. Espoo: Helsinki University of Technology.

O'Rourke, J., A. Aggarwal, S. Maddila and M. Baldwin. 1986. An optimal algorithm for finding minimal enclosing triangles. *Journal of Algorithms* 7 (2): 258–269.

Peura, M. and J. Iivarinen. 1997. Efficiency of simple shape descriptors. In *Aspects of Visual Form*. World Scientific, 443 – 451.

Rosin, P. L. 2003. Measuring shape: ellipticity, rectangularity and triangularity. *Machine Vision and Applications* 14 (3): 172–184.

Sarfraz, M. and A. Ridha. 2007. Content-based Image Retrieval using Multiple Shape Descriptors. In: *IEEE/ACS International Conference on Computer Systems and Applications*, 730 – 737. Amman, 13. – 16 May

Schnurrbusch (1991): Schlaggestaltung und Schlaggröße aus landeskultureller Sicht. *Feldwirtschaft* (5): 206–208.

Zenger, X. (2011): Agrarstrukturentwicklung in Bayern. Bavarian State Research Center for Agriculture. online available at: http://www.lfl.bayern.de/publikationen/daten/informationen/p_41901.pdf, checked on 10.5.13.

Zunic, J. and P.L. Rosin. 2004. A new convexity measure for polygons. *IEEE Transactions on Pattern Analysis Machine Intelligence* 26 (7): 923–934.

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