Happich, Georg; Lang, Thorsten and Harms, Hans-Heinrich

Model based loading state definition for parallel operated harvesting

Harvesting operations are increasingly characterized by parallel harvesting and loading processes. Both processes must be controlled concurrently. To enable an automated loading a model based approach for monitoring the loading state has been analysed. Concerning that the partly adverse harvesting conditions reduce the efficiency of computerized vision based monitoring, model based loading might have the ability to play a future key role. This paper depicts the definition of the loading state; its loading model approaches and derives an overview of the research project which is promoted by the German Research Foundation.

Keywords
GPS-based relative position control, spout control, precision overloading, bulk heap software model, loading process model, cooperating machinery

Abstract
Landtechnik 66 (2011), no. 3, pp. 205–208, 2 figures, 1 table, 10 references

In agriculture harvesting is often parallel operated. The performance of the loading process is a significant parameter for qualifying the overall harvesting process. The drivers' attention must firstly focus on the harvesting, secondly on the loading process. Machine collisions have to be strictly avoided. Additionally, to increase the utilization and the capacity of the machinery, harvesting is carried out by night, which supplementary exhausts the machine operators. Concerning the growing dimensions of harvesting machines as well as of transportation units, gaining insight into the transportation units is hindered. Furthermore higher working speed and the usage of bigger Transportation units is engaged. ([1], [2], [3])

The Institute of Agricultural Machinery and Fluid Power developed the automated position control of the spout of a forage harvester during a former research project (c. f. [4]). Controlling the overall loading process automatically, represents a consecutive improvement, which allows loading without interaction and manual control by the machine operator. Looking forward to an automatic loading system a new research project has been executed, and a throughput-related loading system has been developed and scrutinized. The basic components of this model based system are the relative position of the vehicles, and the loading point position control. Regarding the vehicle's relative position and the actual orientation of the spout, the real loading point is calculated. In opposite to stand-of-the-art automatic loading systems ([5], [6]), which uses optical sensors for the direct measurement of the loading state, the distribution of the loaded crop is approximated model based.

The throughput and the loading point are estimated by field-proven sensors, and the loading state is modelled in an approximation. Setting an expedient sequence of loading points, the transportation unit is gradually filled.

Usable model of the loading geometry, the distribution and the loading process

Developing a model to approximate the distribution and the geometry of the load is an important part of the research project. During the project field trials were carried out, focussed on the analysis of the crop cone geometry and the crop cone interaction. Three assumptions were qualified, which are discussed in [7].

- The bulk heap gradient on the slope heading the crop stream is directly influenced by the properties of the crop material. The gradient of the front shoulder of the crop cone is in the range of 31° to 40°.
- The gradient on the averted side is affected both by the material properties and the impact vector of the crop stream. If the impact vector exceeds the value of 45°, the gradient is saturating in a range of 35° to 40°.
- The deviation of the apex coordination (eke. heap apex shifting) and the gradient of the crop cones can not be separated, and a joint concept must be achieved to model the deviation. On balance the crop cone's and the impact point of the crop stream correlate only in exceptional cases.

Leaning towards the assumptions of Schulze and Landry in [8], [9] numerical simulation methods were not used. These methods in general consume a high amount of computing power, which is normally not available at harvesting machinery. During the project a new model approach has been embarked, describing the geometry via elementary 3D functions, such as cones, paraboloids and hyperboloids.

A first approach has been implemented, defining single bulk heaps as split, two phased crop cones. These cones consist of a circular cone and an elliptic cone. As a detailled derivation and discussion exceeds the scope of this work, the work of [10] shall be appointed.

The loading state is approximated with a two dimensional matrix. Every single element of the matrix is defined as discrete coordinates of the transportation unit. The value of the element correlates with the loading height at the coordinates. Thereby the matrix defines the distribution via an elevation profile of the load, and the volume of the load can easily be calculated.

Whilst the loading state is defined by the elevation profile, the loading process is approximated as the sequentially calculation of the loading state. Therefore discrete loading volume is added to the loading state. Concerning the value of the volume, the loading vector and the actual loading state, the distribution of the additional volume is estimated and the new, combined loading state is defined (**figure 1**). The estimation is separated into three steps.

1. Calculation of the real loading point: Every loading point is defined as coordinates inside the transportation unit. Using the loading point, the actual loading state and the impact vector of the crop stream, the real loading point is assumed. It defines the coordinates of the generated, new crop cone apex, which is approximated by the split cone. This cone is defined – as the loading state – via a two-dimensional matrix, the matrices dimensions and the correlation to the coordinates in the transportation unit are even.
2. Estimation of the Loading height and the distribution of the load: Using the definition of the geometry of the single cone (c.f. **Figure 2**), the real loading point and the actual loading state, the height of the apex and the distribution of the added load is calculated.

Defining the combined loading state: The distribution of the load is described by the elevation profile. The dimensions and conventions of the profile are the same as of the matrices given above. Adding the matrices defines the combined loading state, concerning of the actual loading state and the additional volume.

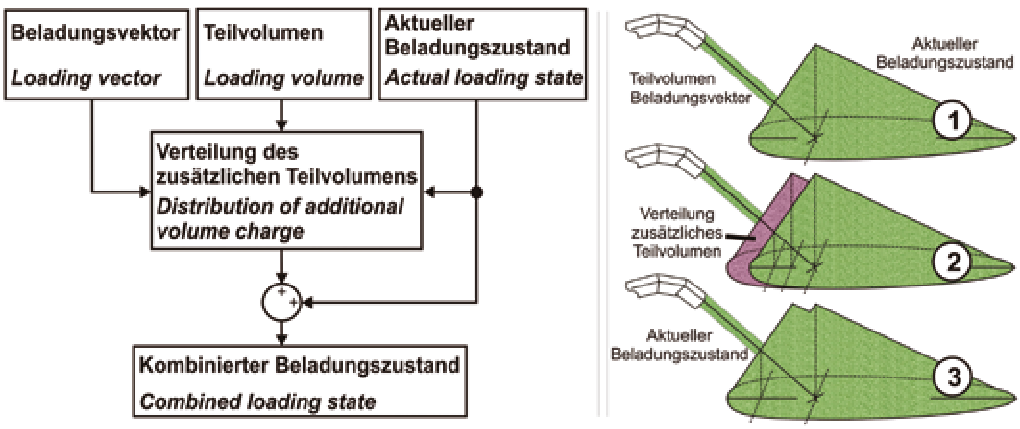
Defining the loading state

As figured above, the loading state is calculated by adding the matrices, which describe the loading state and the additional volume. The distribution of the additional volume is calculated using an iterative approximation method. The sequences of the method are given in **figure 2**. The parameters used in one single iterative approximation are labelled with an additional (*). Furthermore **tabular 1** derives an overview of the used abbreviations and the meanings of the parameters.

The sequences shown in **figure 2** are given as follows:

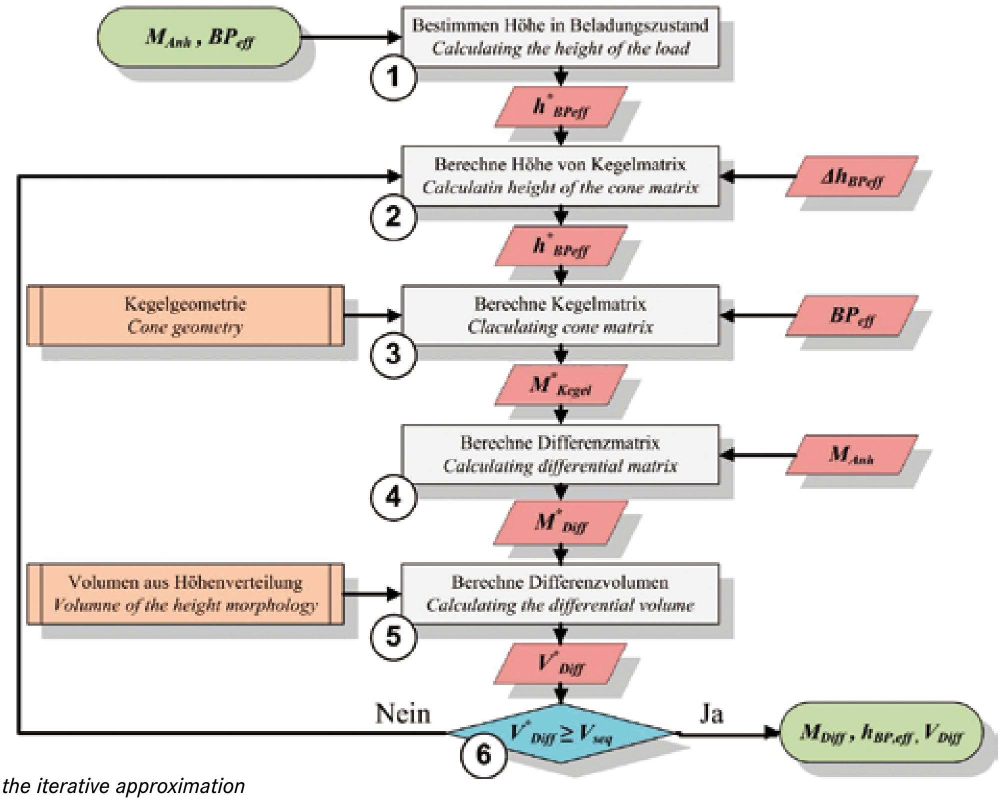
3. The height of the loading state at the coordinates of the real impact point is calculated.
4. The calculated height is increased by a preset difference $\Delta h_{BP_{eff}}$ = 1 cm, leading to the crop cone height $h^*_{BP_{eff}}$.
5. Using the geometrical definition and the real loading point the elevation profile of the matrix M^*_{Kegel} is estimated, which describes a single cone of the height $h^*_{BP_{eff}}$ and the basal origin coordinates of BP_{eff}.
6. The distribution of the load is given by M^*_{Diff}. It is defined as the difference of the matrices M^*_{Kegel} (s.a.) und M_{Anh} (the loading state). M_{Diff} is generally positive, and values less zero are set to zero.
7. The volume V^*_{Diff} is calculated using the elevation profile of M^*_{Diff}.
8. The real loading height and the distribution are achieved, when V^*_{Diff} is exceeding the added volume (V_{seq}). The new loading state is estimated by adding the given matrices.

Fig. 1



Discrete loading state definition

Fig. 2



Operation chart of the iterative approximation

Compared to usual approximation methods this approach has one main advantage: the loading state is described, but changes in the size of the added volume and eventual upcoming changes of the loading point can be estimates as well.

Discussion and conclusion

This article derives an overview of a new approach for modelling agricultural crops, which is suitable for loading processes. The approach was scrutinized in field trials. During these trials six operators were driving the transportation units, differing in driving skill and agricultural knowledge. The relative posi-

Table 1

Abbreviation list

Bezeichnung *Abbreviation*	**Bedeutung** *Meaning*
V_{seq}	(Sequentiell) zugeführtes Teilvolumen *(Sequential) additive volume*
V_{Diff}	Berechnetes Volumen der Verteilungs- bzw. Differenzmatrix (M_{Diff}) *Calculated volume of the distributional differential resp. differential matrix*
BP_{eff}	Effektiver Beladungspunkt in Form der Koordinaten auf der Anhängerfläche *Effective loading point*
M_{Anh}	Matrix des Höhenprofils der Beladung im Anhänger (Beladungszustand) *Matrix of the height morphology inside the trailer (loading state)*
$h_{BP_{eff}}$	Schütthöhe der entstehenden Gutverteilung oberhalb des effektiven Beladungspunkts *Height of the distribution at the coordinates of the effective loading point*
$\Delta h_{BP_{eff}}$	Iterationsgröße, Annäherung der Schütthöhe in der Größenordnung von $\Delta h_{BP_{eff}}$ *Iterational value, used to increase the distribution height*
M_{Kegel}	Theoretische Gutverteilung bei gegebener Schütthöhe ($h_{BP_{eff}}$) und effektivem Beladungspunkt (BP_{eff}) *Theoretical cone geometry concerning the given height ($h_{BP_{eff}}$)*
M_{Diff}	Differenzmatrix der Höhenprofile von Beladungszustand und der rein auf die Schütthöhe und den Beladungspunkt bezogenen Gutverteilung (M_{Kegel}) *Differential matrix of the loading state and the theoretical cone geometry*

tion of the vehicles was varied and two loading strategies were tested. The first strategy implied a constant relative position of the vehicle, the second one a constant relative orientation of the loading spout. Besides the longitudinal position of the vehicles the lateral position was changed. After testing the automated loading system, the calculated distribution of the crop was compared to the real distribution, regarding to the elevation profile.

The functionality of the automated loading system was proven only with few limitations, such as malfunctions of the positioning system. The median deviation of the elevation height between the real and the modelled distribution is in a range of less than 15% of the maximum loading height. Considering the variation range of the trials and the massive level of crop cone abstraction, the results of the comparison are very promising. The given approach gives best opportunities for further development and a prosperous usage.

As an outlook the further enhancement of the approach is planned, by means of the knowledge-based integration of the impact of disturbance values. Using a modular integration method, the loading processes can be fundamentally facilitated, firstly regarding to agricultural crops and secondly to materials utilized in other process engineering technologies.

Literature

[1] Buckmaster, D. R.; Hilton, J. W. (2005): Computerized cycle analysis of harvest, transport and unload systems. Computers and Electronics in Agriculture 47(2), pp. 137–147

[2] Wallmann, G.; Harms, H.-H. (2002): Assistenzsystem zur Überladung landwirtschaftlicher Güter. Landtechnik 57(6), pp. 352–353

[3] Lang, T.; Göres, T.; Jünemann, D.; Vollrath, M.; Werneke, J.; Huemer, A. K. (2009): Untersuchung von „Human Factors“ bei Landmaschinen. Landtechnik 64(1), pp. 58–60

[4] Weltzien, C. (2009): Assistenzsystem für den Überladevorgang bei einem selbstfahrenden Feldhäcksler. Dissertation. Forschungsberichte des Instituts für Landmaschinen und Fluidtechnik. Shaker Verlag, Aachen

[5] Kirchbeck, A.; Lahmann, D. (2010): Automatisierungsbeispiel: Bildgebende Systeme im Feldhäcksler. KTBL-Tagung 2010, S. 110–116

[6] Madsen, T. E.; Kirk, K.; Blas, M. R. (2009): 3D camera for forager automation, 67th Conference Agricultural Engineering LAND.TECHNIK AgEng 2009, VDI-Verlag, Düsseldorf, 147–152

[7] Happich, G.; Lang, T.; Harms, H.-H. (2009): Loading of Agricultural Trailers Using a Model-Based Method. Agricultural Engineering International: The CIGR Ejournal, vol XI., Manuscript 1187

[8] Schulze, D. (2002): Fließeigenschaften von Schüttgütern mit faser- und plättchenförmigen Partikeln. Schüttgut 8(6), S. 538–546

[9] Landry, H.; Thirion, F.; Lagüe, C.; Roberge, M. (2006): Numerical modelling of the flow of organic fertilizers in land application equipment. Computers and Electronics in Agriculture 51(1-2), pp. 35–53

[10] Happich, G.; Lang, T.; Harms, H.-H. (2010): Modellierung landwirtschaftlicher Güter für parallele Überladeprozesse. 68. Internationale Tagung Land.Technik des VDI-MEG, VDI-Verlag, Düsseldorf, S. 279–292

Authors

Dipl.-Ing. Georg Happich is research associate, **Prof. Dr.-Ing. Thorsten Lang** is the acting director of the Institute of Agricultural Machinery and Fluid Power (ILF) at Technische Universität Braunschweig (former directed by **Prof. Dr.-Ing. H.-H. Harms**), Langer Kamp 19a, 38106 Braunschweig, e-mail: g.happich@tu-bs.de, http://www.tu-braunschweig.de/ilf