SPATIAL MODELLING OF AGRICULTURAL CROPS FOR PARALLEL LOADING OPERATIONS

Georg Happich, Thorsten Lang, Hans-Heinrich Harms

Institute of Agricultural Machinery and Fluid Power,
Technische Universitaet Braunschweig,
Braunschweig, Germany

ABSTRACT

There is a trend in agricultural engineering towards high-performance harvesting machines with growing operating width and throughput. As much as performance and throughput are rising, the transportation units are characterized by increasing transportation volume.

If harvesting and transport are combined in parallel operation (e.g. self-propelled forage harvester), the driver of the harvesting machine and the driver of the transport unit has to pay a high degree of attention to the loading process. But losses of harvesting goods caused by missing the trailer have to be kept at a minimum, the complete transport volume should be utilised and collisions between the involved machines have to be avoided. Loading processes with large-scaled machinery mostly imply that the visibility into the transportation unit is severely limited.

The main aim of the presented research project is to develop and analyse the potential of model based loading exemplified on a forage harvester and a corresponding transport unit. The forage harvester had been used as the prototype for a GPS-based position control of the spout. The model based loading means an enhancement of the automation of the loading process.

First objective of this research project is the development of a software model of the heap of bulk goods. Basal analysis on heaps of agricultural goods like grass and maize silage are essential. By combining the software model, the space model of the transportation unit and the throughput, the current status of loading is predictable and different loading strategies can be spotted, tested and scrutinized with regards to efficiency and the facilitation of work.

This article derives a general overview of the research; including a short introduction concerning the overall trends of automation in agriculture In addition to the set up of the loading principle exemplified field trial results as well as the model concept will be given.

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

INTRODUCTION

Following a common trend in agricultural engineering size and weight of harvesting machines are increasing as well as working width and throughput are rising. Larger machine size usually causes higher financial investments and relative high operating costs. To generate a maximum of harvesting profit, harvesting machines – as well as any other high performance machine – have to be run at the most efficient configuration as possible as well as at a high amount of operating time per harvesting period.

If harvesting and transport are combined in parallel operation, the overloading process is of another particular importance for the efficiency of the whole harvesting process. Constant vigilance and high concentration is required from the driver in order to avoid losses, overfilling or collisions between the vehicles. With increasing speed and dimensions these demands increase as well (Buckmaster and Hilton, 2005; Wallmann and Harms, 2002). The interaction of harvesting, loading, transport and unloading results in countless possibilities for combining machinery regarding to e.g. transportation capacity or system efficiency (Buckmaster and Hilton, 2005). Besides the complexity of the whole harvesting logistics the overloading process in parallel operation implies several difficulties. Firstly, both drivers - of the tractor and of the harvesting machine – have to work in a well coordinated team. They have to pay high attention on their driving path and overloading process. Regarding the normal arrangement of the cockpit of a tractor and a harvesting machine, the driving path is in front of the machines, but the overloading process happens backwards to the drivers. Due to this, every time they increase their attention to the overloading process, their attention to their driving direction declines.

Figure 1: Self propelled forage harvester and tractor-transport unit

Secondly, due to the increasing dimensions of agricultural machinery, it is getting more difficult to take insight into the transportation unit (cf. Figure 1). Neither the driver of the tractor nor the driver of the harvesting machine has full insight into the units, generally only the edges and the last fragments of the side walls are visible. Therefore they have to act on expertise. Especially when the harvesting machine has to be run during night, the concentration on the overloading process narrows the performance of the whole harvesting process (Wallmann and Harms, 2002).

For this reason, the automation potential during the parallel loading process is being investigated at the Technische Universität Braunschweig. To meet this purpose the Institute of Agricultural Machinery and Fluid Power (ILF) and the Institute for Control Engineering (IfR) developed a loading assistance system.

Assistant system for the overloading process (ASUL)

The prototype of the ASUL assistant system allows a closed loop loading position control of the spout of a forage harvester. As depicted in Figure 2 four GPS-receivers are fixed on the roof of the harvester, three receivers are mounted upon the tractor. The raw position signals (as NMEA-strings) are computed in an industrial PC placed on the harvester. Because of the minor distance between harvester and tractor the inherent deviation of the raw position signals are very equal for all receivers and can be eliminated via software. The deviation of the relative positions of the vehicles is about 5 centimeters, while the failure in absolute position is of secondary importance. On the harvester a dSpace-PC is used to compute the control of the loading point. Via the ControlDesk software every position in the tumbril can be defined as the aim of the crop-stream, while the dSpace controls the appropriate spout position via a Matlab/SIMULIK-model so that the stream hits the position. The system works within the given parameters. The spout control allows position accuracy up to 50 centimeters. (Weltzien, 2009)

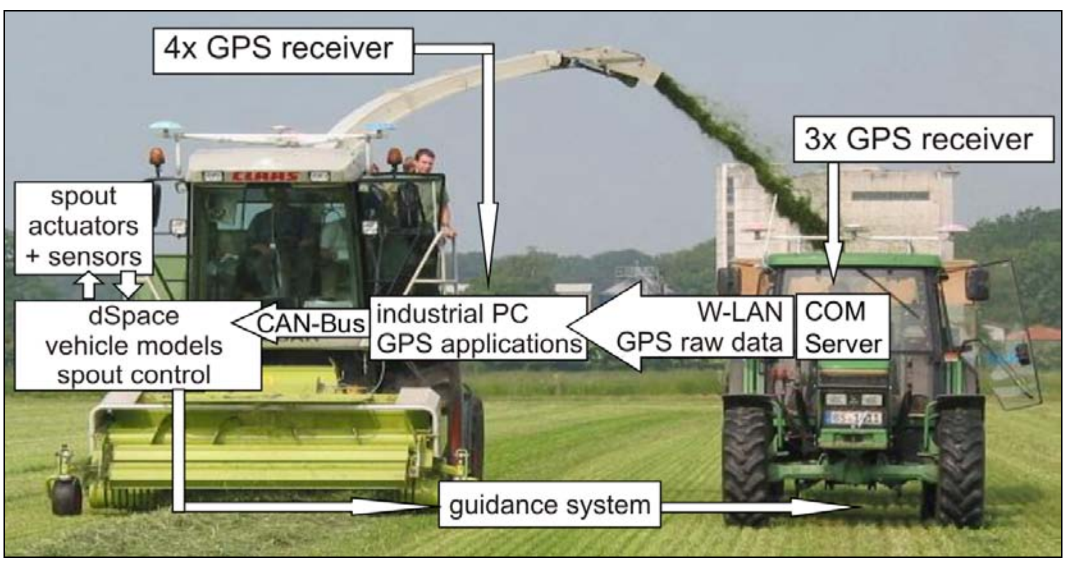

Figure 2: Set up of the ASUL assistance system

Qualifying the ASUL potential for the automation of overloading

Modern harvesting machinery is generally equipped with an increasing number of sensors. The data recording of these sensors is used for miscellaneous objectives. The applications vary from telemetric systems according to the performance data (e.g. operation speed, machinery position) and machine settings (e.g. knife drum speed, throughput) to system reliability monitoring, which mostly is carried out by condition management and machine warnings (e.g. oil pressure, oil temperature) (Krallmann and Foelster, 2002; N.N.08, 2008; Amiana et al., 2008). With regards to the vulnerability of low level optical sensors to the influences of agricultural environment (e.g. Graefe et al., 2005) and the sensor equipment of agricultural machinery, the investigation of model based loading strategies based on sensors actually mounted on harvesting machinery has been initiated. Therefore another research project started in 2007, enhancing the ASUL system by the usage of throughput related model based loading methods.

PRINCIPLE OF THROUGHPUT-RELATED MODEL BASED LOADING

Model based loading is one consequent continuance of developing an automated assistance system for the loading process. The shown concept involves, that the loading status ought to be emulated relating to the throughput. The following paragraph deals with the set up of the throughput-related loading, followed by the discussion of exemplified field trial results as well as the model concept being used.

Main components of the model based overloading system are parts of the ASUL system like the determining of the relative position and the loading point control. The system is being supplemented by throughput-related loading strategies. With a potentiometer the distance between the intake rollers is measured. The throughput volume is forecasted by taking the geometry of the intake channel into account. The trailer can be divided into several discrete volume spaces. By generating and achieving loading points the discrete spaces are to be filled up to the maximum load of the trailer. Regarding the throughput and the effective loading position a software model estimates the loading state inside the trailer, until it is filled at maximum rate. (cf. Figure 3)

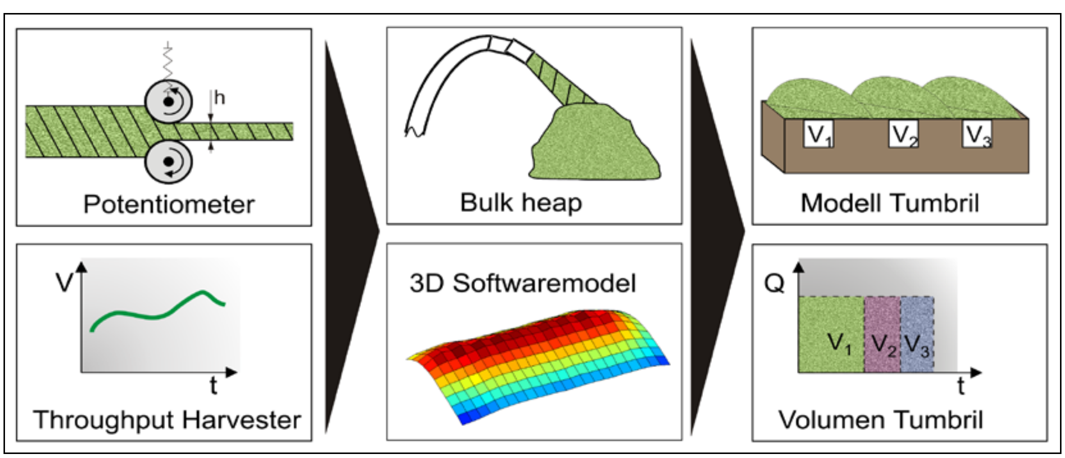

Figure 3: Set up of model based overloading

ANALYZING BULK HEAP REFERENCES

Within the research project “model based loading of agricultural trailers” several field trials are divided by their main focus. Firstly, field trials are used to acquire geometric references of bulk heaps for the software model. Secondly, field trials have the focus of scrutinizing the software model as well as the loading strategies with regards to precision, efficiency and facilitation of work. At the current state the verification of the automated loading and the software models is still in progress, therefore this paper will only derive an overview of the set up of field trials, some results as well as the software model concept of the automated loading. The results of the geometry analysis are given in this chapter.

Parameter definition

In this paper three main parameters and their parameter linking are analyzed. Due to the limited number of trials the results are not statistically confirmed, but the tendencies and theses could be proven. The analyzed parameters are firstly the bulk heap gradient; secondly the impact angle and thirdly the bulk heap apex shifting. Figure 4 depicts the parameter definition.

The bulk heap gradient is the gradient of the heap facing the basement of the trailer. The impact angle is the lowest angle being enclosed firstly by the trailer basement and secondly by the loading vector, which is described by the spout position, the trailer position and the achieved loading point. Physically the impact angle cannot be higher than 90° and cannot decrease down to 0°. The bulk heap apex shifting is the offset of the heap apex relating to the trailer basement, which means the offset between the loading point preset and the emerging heap apex in bird’s eye view.

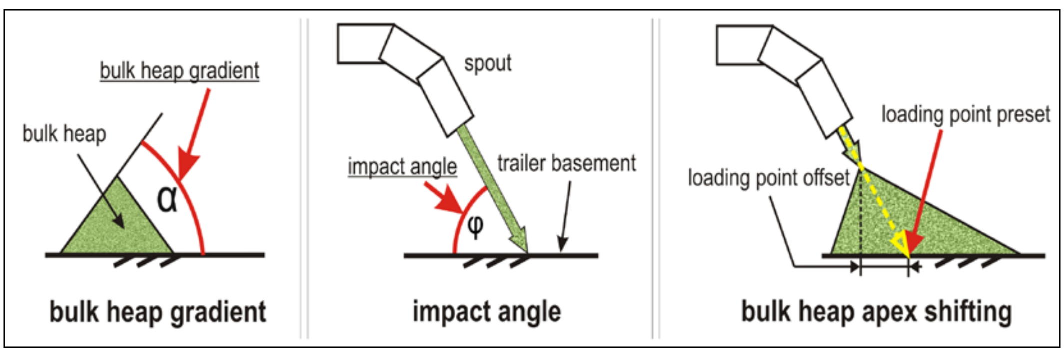

Figure 4: Bulk heap parameter definition

Results and discussion of the bulk heap analysis

Regarding to the parameter definitions in the first approach two types of parameter linking have been analyzed. The decisive theses have been:

1. The lower the impact angle, the lower the gradient.
2. The lower the impact angle, the more the apex shifting.

The following figures (Figure 5, Figure 6) depict some of the meaningful results of the grass harvesting period 2008 as well as the trend lines. The shown data are based on the digital replicas measured during field trials. The test range of the impact vector is from 32 to 71 degrees. For the shown gradients as well as the bulk heap apex shifting the direction of the loading vector has been taken into account. For the sake of completeness the trends being monitored during the maize harvesting period have been very similar.

Figure 5 derives the data and the trend lines for the front side as well as the back side gradient in correlation to the impact vector. The front side denominates the gradient facing the loading vector; the back side gradient is averted to the crop stream. Concerning the results the proof of the first thesis ought to be asserted. But as the back side gradient is increasing from 12 to about 36 degrees, the results for the gradient of the front side of the bulk heaps do not clarify the given assertion.

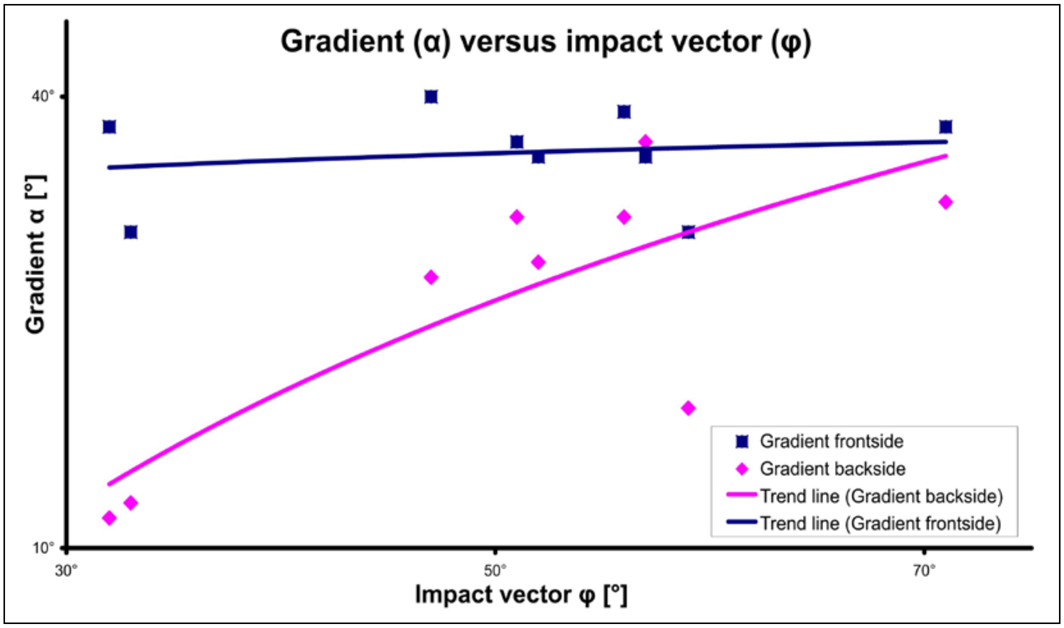

Figure 5: Bulk heap gradient versus impact vector

Although the measured front side gradients indicate the increasing tendency over the tested range, the variation of the data is higher than the increment of the trend line. With reference to the field trials set up and the physical growing process of the bulk heaps in the trailer, this effect can be explained facile. During the growing process the loading point preset has not been changed. Therefore – without forestalling the results of Figure 6 – the impact point in general is on the slope of the emerging bulk heaps while the heaps are growing contrary to the crop stream. This involves, that on the front side of the bulk heap the slope is continuously generated anew. The results meet the experience made during all of the field trials, where the gradient on the front side is more affected on the material than on the process parameters. On the side being averted to the crop stream one may presume that the gradient is increasing up to a saturated maximum level at about 39 degrees.

Figure 6 derives the results and the trend line of the analyses concerning the second thesis. The thesis can be assumed to be proven. Along the tested range the apex of the bulk is decreasing from 1.3 meters for low impact vectors down to only 20 cm for the highest impact vector of 71 degrees.

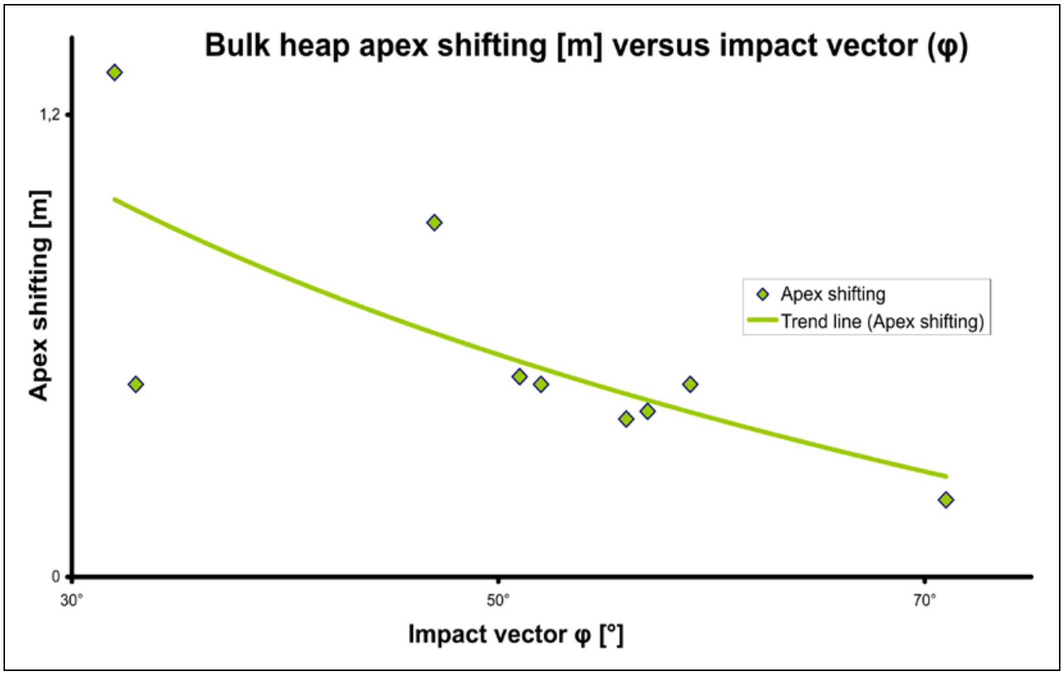

Figure 6: Bulk heap apex shifting versus impact vector

MODELLING THE LOADING PROCESS

Modeling the form of bulk heaps via CFD and DEM techniques will not take place during the research. As Schulze (Schulze, 2002) and Landry (Landry et al., 2006) ascertained, the less homogeneous the bulk material is the more inhomogeneous is the inner friction force. Hence to that, modeling or even approaching the load of a trailer via DEM needs an enormous amount of computing power, which usually is not available on agricultural mobile machinery. A geometrical approach has been chosen. The all-important parameters which have to be implemented in the software model are the geometrical form of the bulk heaps as well as the build up behavior of the virtual load.

Bulk heap model concept

The bulk heap software model concept is based on an approach using only elementary mathematical 3D functions. These ought to be e.g. hyperboloids, cones or hyperbolic paraboloids. The main advantages of this approach are the inherent functions, which are all well known and easy to be adapted, very easy to be implemented and to be varied as well as very fast in computing time (because the functions are uniformly continuous). Additionally they are exceedingly qualified to be combined, so that relatively complex geometry (e.g. interacting bulk heaps) can be compiled. A first approximation includes a bipartite straight cone. Concerning the field trial results the front side of the bulk heap is described in a right circular cone, the averted side is depicted by an elliptic cone (cf. Figure 7).

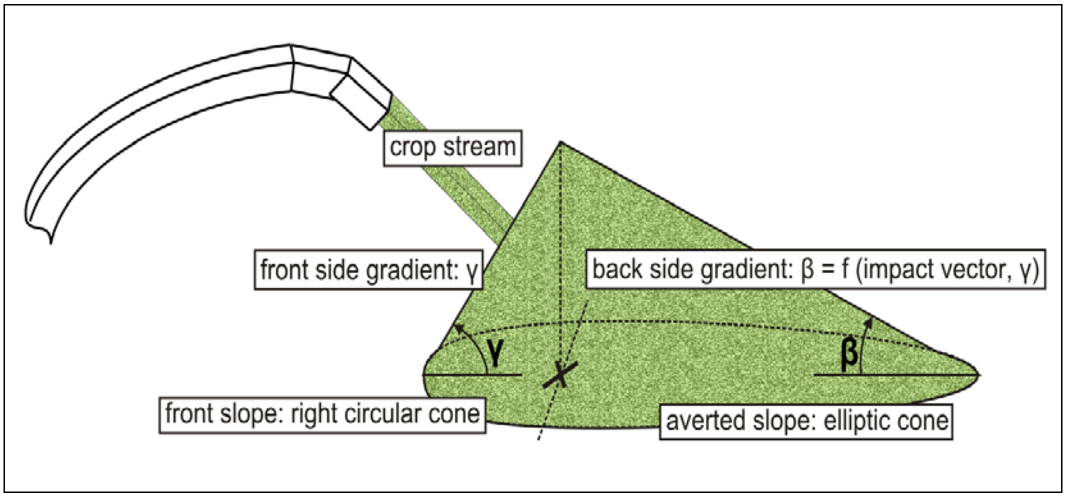

Figure 7: Geometrical bulk heap definition using a bipartite right cone

Loading state definition

Besides the definition of the geometry the interaction of the actual loading state and the additional volume must be considered. Therefore the loading state definition contains the loading state build up, which means the temporal assembly of one heap as well as the interaction between several heaps. To deal with both aspects a general approach has been utilized.

To define the general loading state three main parameters are to be considered: the loading vector of the crop stream, a predefined discrete loading volume and especially the actual loading state. The virtual loading space is to be filled stepwise; the step width is predefined by the size of the discrete loading volume (cf. Figure 8). For every step the actual loading state and the loading vector are analyzed; the impact coordinates are calculated; they describe the coincidence between the actual loading state and the impact vector. These parameters are used to estimate the center coordinates – the new apex - of the emerging bulk heap. Regarding to the single bulk heap geometrical model and the center coordinates the distribution of the discrete loading volume is computed. The distribution of the discrete loading volume as well as the actual loading state is processed in 2D-matrix-descriptions; both matrices are added and for every step the actual loading state is generated.

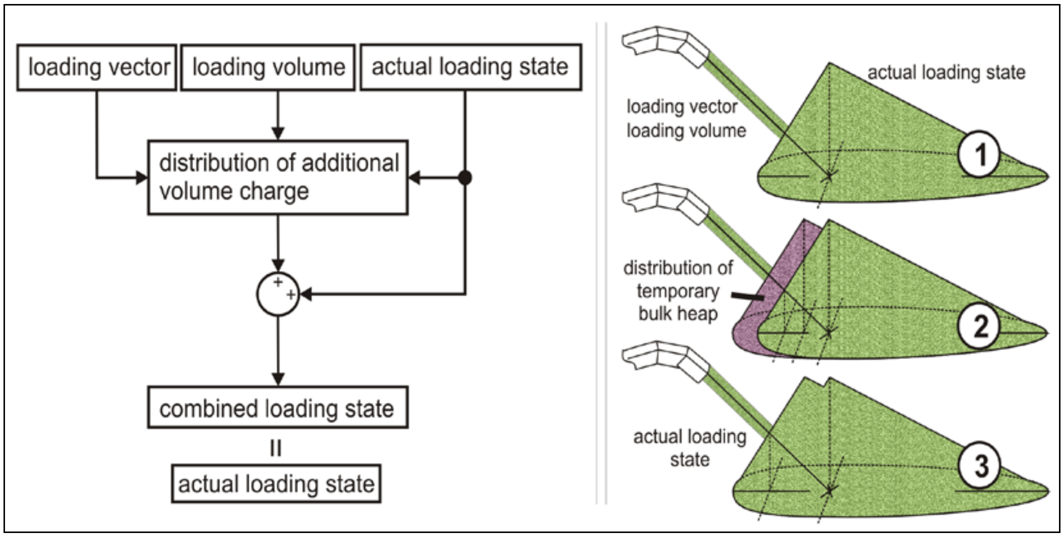

Figure 8: Software concept of the loading state definition

Loading Strategies

Focusing the harvesting period 2009 simple loading strategies have been implemented in the ASUL experimental vehicle. For every trailer one virtual starting loading point is defined, firstly on the front or on the back side of the trailer. Based on this starting point the loading point is shifted along the longitudinal axis of the trailer, whereby every loading point is fixed until the model assumes that the loading at this discrete point has reached its maximum. Figure 9 depicts the principle in a sectional view in the longitudinal axis of the trailer. The strategy starts with the filling of the first approximated loading point (Figure 9, a, b) and continues by the further shifting of the loading point (Figure 9, c, d).

Figure 9: Implemented loading strategy

3D model accuracy

After the loading process is completed a laser scanner is used to merge a 3D-replica of the real loading distribution. This distribution is being compared to the calculated virtual load. Within this comparison the model is being validated by means of the overall derivation of the distribution of the loaded volume. The maximum height difference, its standard deviation and the median for the difference is taken into account.

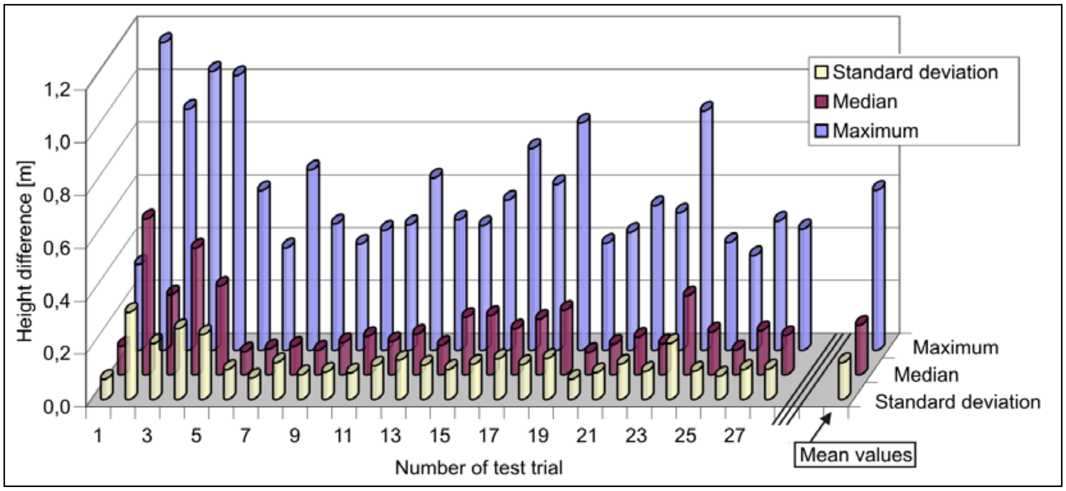

Figure 10: Maximum, median and standard deviation of the compared height difference

For the field trials a relatively small trailer with a maximum load of 8 tons has been used. Regarding to the small size of the trailer the maximum height difference of up to 1.13 m (cf. Figure 8) equates a deviation of about 45 % of the overall maximum height of ca. 2.5 meter. But the mean value for the maximum difference over 29 trials is slightly more than 60 cm. Considering the median of the differences as well as the standard deviation - which have been analyzed for each trial - the results imply an adequate overall distribution of the virtual load. The mean value of the median difference is 20 cm and the standard deviation is at about 14 cm (Figure 8). The mean median difference is less than 10 % of the overall maximum height.

A mean abundance distribution function of the height differences has been determined. The function implies that in general more than 1/3 of the measured height differences are less than 10 cm (cf. Figure 9), nearly 60 % of the load height differences is less than 20 cm, which means a deviation of 10 % of the maximum overall height of the load. More than 75 % of the measured values vary in a range of up to only 30 cm.

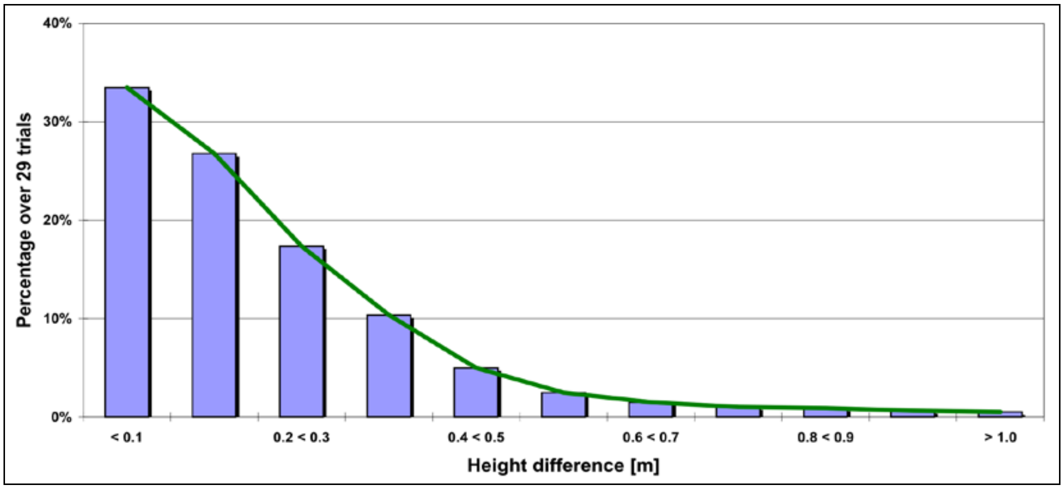

Figure 11: Mean abundance distribution function of the height differences

CONCLUSION

An auxiliary system for loading agricultural goods in parallel process has been developed at the Technische Universitaet Braunschweig. The functionality of the auxiliary system has been confirmed in harvesting tests during the last five years.

The consecutive investigation of the automation potential of the loading process implied the option of research on loading models to realize model based parallel loading operations. Therefore a new research project started in 2007 to investigate model based loading in parallel operation. During this project software models have been developed describing the assembly of bulk heaps under influence of agricultural environment. Focusing on both shape and assembly, reference measurements of bulk heaps have been taken in field trials. The influences of the crop stream vector on bulk heap assembly have been analyzed varying the loading set point on the slope as well as the length of the stream. The development of the bulk heap models has been advanced, so that currently the geometrical model is a bipartite right cone; the build up process is approximated by the incremental addition of discrete volume sets. Actually the model based loading is scrutinized regarding to the correlation of the spatial model and the real distribution inside the agricultural trailers. The first results regarding the height difference between the model and the 3D replica of the emerged distribution of the load are promising a notable high analogy. Using the first much generalized model approach about 60 % of the virtual distribution is within a variance band of 20 cm, which is about 10 percent of the overall height of the virtual load.

Considering the development of vision based loading systems in the last years (e.g. CLASS Auto Fill, New Holland IntelliFill; cf. Madsen et al., 2009; N.N.09, 2009), the vulnerability of these systems has become manageable. This progress has been driven by the decreasing purchase costs of the sensor hardware (stereo or time-of-flight camera) and the development of efficient image processing algorithms and increasing performance of the applied data processors. Until now the redundancy of neither the model based nor the vision based approach is given. One possibility to enhance the automated loading might be the combination of both approaches into an integrated redundant control system.

ACKNOLEDGEMENTS

The research project ‘model based loading of agricultural trailers’ is funded by the Deutsche Forschungsgemeinschaft DFG (German Research Foundation) and supported by the Co. Claas SE via the loan of a forage harvester and technical support. The support in GPS-Technology is carried out in a co-operation with the IfR and Co. geo++.

REFERENCES

Buckmaster, D. R., Hilton J. W., 2005. Computerized cycle analysis of harvest, transport and unload systems, Computers and Electronics in Agriculture 47, pp.137-147.

Wallmann, G., Harms, H.-H., 2002. Assistenzsystem zur Ueberladung landwirtschaftlicher Gueter, Landtechnik 57, pp. 352-353.

Weltzien, C., 2009. Assistenzsystem für den Ueberladevorgang bei einem selbstfahrenden Feldhaecksler, Shaker Verlag, TU Braunschweig Dissertation Thesis, Aachen.

Krallmann, J., Foelster, N., 2002. Remote service systems for agricultural machinery, Proceedings of the 2002 Conference of the ASABE, pp. 689-694, Chicago, Illinois.

N.N.08, 2008. Produktivitaet zaehlt, brochure of the Claas Lexion 580 570 570 C combine harvester, s.l., pp. 18, 35, as of December 2008.

Amiana, C., Bueno, J., Álvarez, C. J., Pereira, J. M., 2008. Design and filed test o fan automatic data acquisition system in a self propelled forage harvester, Computers and Electronics in Agriculture 61, pp. 192-200.

Graefe, F., Schumacher, W., Feitosa, R. Q., Duarte, D. M., 2005. FILLED - A Video data based fill level detection of agricultural bulk freight, ICINCO 2005 Proceedings Vol. III.

Schulze, D., 2002. Fliesseigenschaften von Schuettguetern mit faser- und plaettchenfoermigen Partikeln, Schuettgut 8, pp. 538-546.

Landry, H., Thirion, F., Lagüe, C., Roberge, M., 2006. Numerical modeling of the flow of organic fertilizers in land application equipment, Computers and Electronics in Agriculture 51, pp. 35-53.

Madsen, T. E., Kirk, K., Blas, M. R., 2009. 3d camera for forager automation, Proceedings of the 67th Conference: LAND.TECHNIK - Agricultural Engineering 2009, pp. 147-152, Hannover.

N.N.09, 2009. *s.t.*, http://www.agritechnica.com/neuheiten.html, s.l., as of November 2009