Loading of Agricultural Trailers Using a Model-Based Method

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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, usually tractor-pulled trailers, 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 as well as the driver of the transport unit has to pay a high degree of attention to the loading process. Losses of harvesting goods caused by missing the trailer have to be kept at a minimum. The complete transport volume should be utilized and collisions between the involved machines have to be avoided. Overloading processes with large-scaled machinery often imply that the visibility into the transportation unit is severely limited.

In a former project a forage harvester has been used as the prototype for developing a GPS-based position control of the spout. The main aim of the following research is to develop a model based loading strategy exemplified on a forage harvester and a corresponding transport unit. 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 and of the loading process. Basal analysis of 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 regard to efficiency and the facilitation of work.

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

1. 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,
- 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 et al., Wallmann et al.). 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 et al.). 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. Machine collisions must be obviated in order to avoid machinery and process stops or a complete machine breakdown. Therefore 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 normally happens backwards to the drivers. That means, 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. 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 et al.).
For this reason, the automation potential during the parallel overloading process is being investigated at the Technische Universitaet 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 (cf. chapter 1.1).

2. ASSISTANT SYSTEM FOR THE OVERLOADING PROCESS (ASUL)

At the Institute of Agricultural Machinery and Fluid Power in Braunschweig an assistant system, called ASUL, has been developed during four years. The prototype 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 et al.)

2.1 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 based on condition management and machine warnings (e.g. oil pressure, oil temperature) (Krallmann et al., N.N., Amiana et al.). With regards to the vulnerability of low level optical sensors to the influences of agricultural environment (e.g. Graefe et al.) and the sensor equipment of agricultural machinery, the consecutive step for the automation of loading processes was the initial investigation of model based

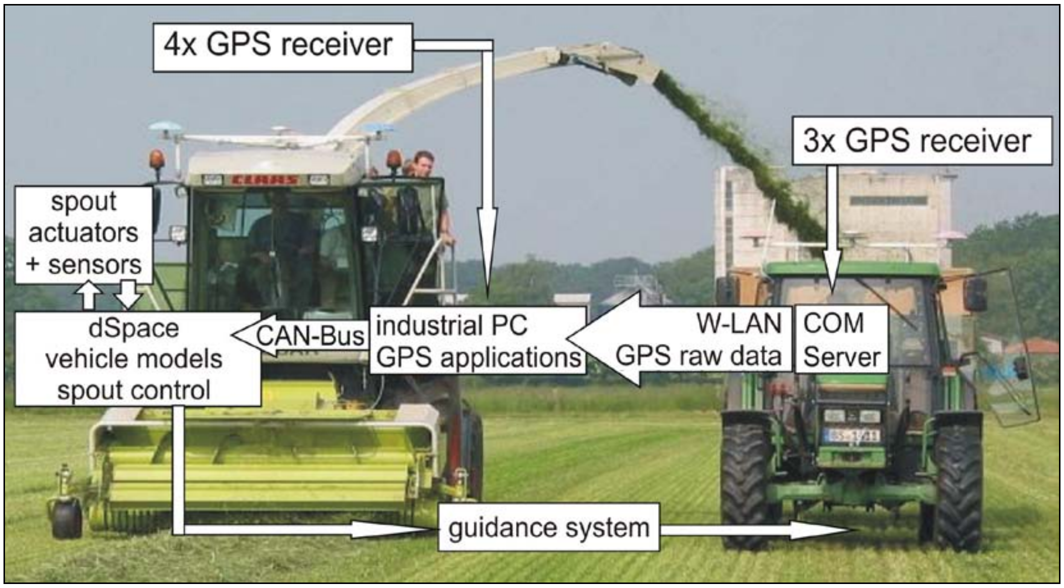

Figure 2: Set up of the ASUEL assistance system

loading strategies based on sensors actually mounted on harvesting machinery. Therefore another research project started in 2007, enhancing the ASUL System by the usage of throughput related model based loading methods.

3. MODEL BASED LOADING OF AGRICULTURAL TRAILERS

Model based loading is the consequent continuance of developing an automated assistance system for the overloading process. Regarding to the problems in visual detection of the filling status and due to the fact, that data logging and electronical assistance is gaining acceptance in agricultural engineering, the loading status ought to be emulated relating to the throughput.

3.1 Set up of the throughput-related model based loading

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)

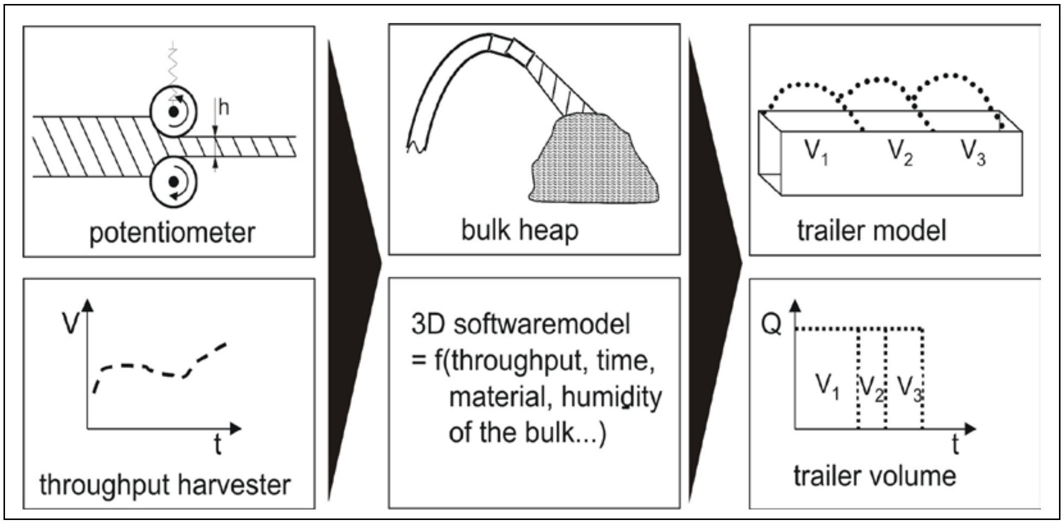

Figure 3: Set up of model based overloading

3.2 Set up of field trials

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 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 automate loading (cf. chapter 4).

3.2.1 Acquiring references of bulk heaps via field trials

Main aspect of the field trials during the first and the second harvesting season is the acquiring of references for the software model of the bulk heaps. Therefore several trials are made as well in grass silage as in maize silage. The influence of the direction of the incoming crop stream was one main, varied parameter. Other trials are used to give an overview of the interacting of discrete bulk heaps:

- which bulk heap is in front,
- which bulk heap is build up first (it is predictable, that building up the first heap in front and the second heap beyond forms an other loading state than the other way around),
- the distance between the discrete bulk heap apexes,
- the crop flow and the gradient of the second heap along the slope of a first heap.

Figure 4 shows the different aspects of the heap interaction.

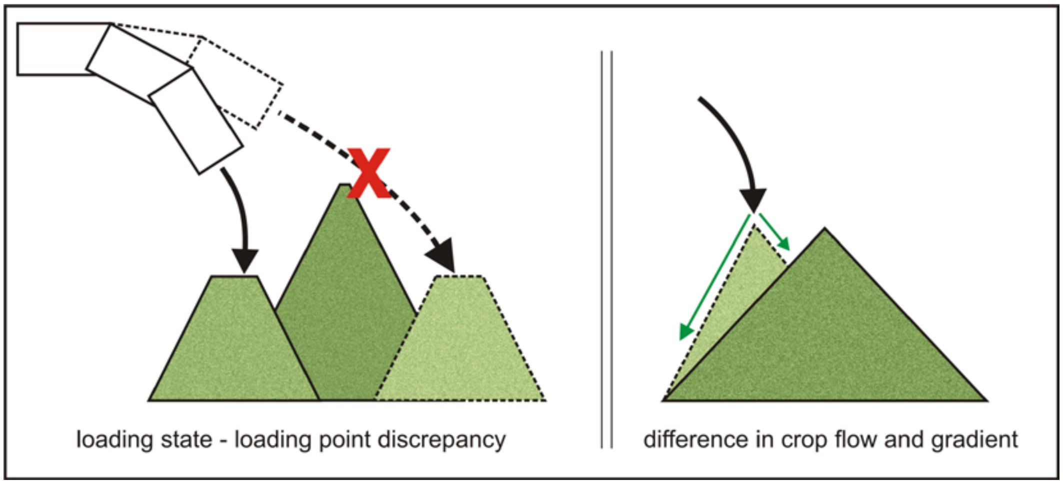

Figure 4: Interaction of heap due to the loading state

The bulk heaps are measured via laser scanning. A laser scanner (Co. SICK) is fixed on a structure on the front loader of a tractor. Along the trailer length the laser is measuring 2D surface lines at a rate about 2 Hz. While the trailer is moving perpendicular to the scanned lines, the 2D surface figures are cumulated to a 3D surface model. By the known size of the trailer, its length, width, and the height of both of the trailer walls and the loading area, the volume of the loading is calculated. In the 3D figure of the loading several parameters of the heap can be shown, e.g. the gradient. Figure 5 gives an overview of the measurement set up and an example of a MATLAB-calculated heap shape.

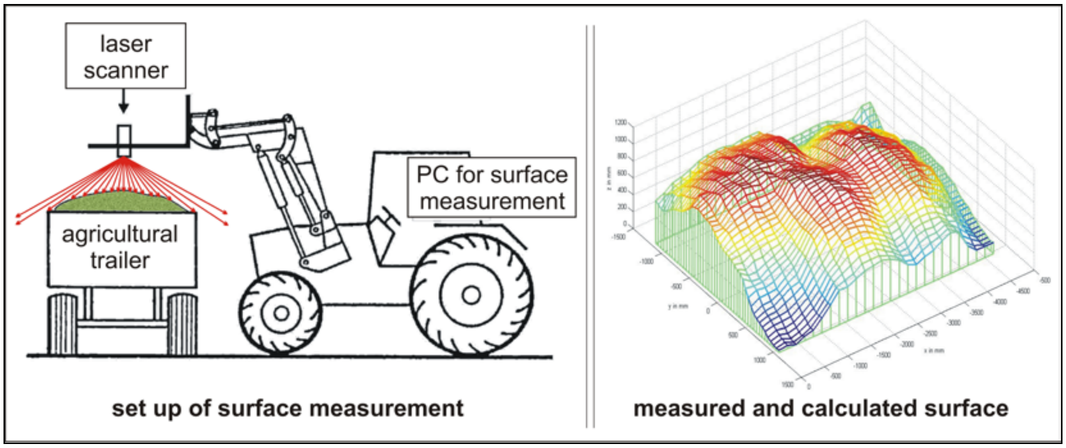

Figure 5: Set up of the surface measurement in field trials and calculated shape

This kind of measurement has two systematic problems. The first one is the distance of the laser scans, means the scanning rate. The form of the heaps can be heavily distorted, i.e. if two scans are made beside one heap apex, only a plateau is calculated and both volume and gradient can not be considered correctly in the heap measurement. Secondly, due to the fact, that the orientation of the trailer to the laser scanner is done eye-controlled, the orientation angle between scanner and trailer varies. Therefore the scanning rate has been enhanced to a rate up to 8 Hz and the calculating software has been improved.

3.3 Field trial results

During the field trials several results have been acquired considering the loading process as well as the bulk heap geometry. In the description of the software model (chapter 3.4) the results regarding the loading process are taken into account. The results of the geometry analysis are given in this chapter.

3.3.1 Parameter definition

In this paper three main parameters and their parameter linking are analysed. Due to the limited number of trials the results are not statistically firm, but the tendencies and theses could be proven. The analysed parameters are:

- the bulk heap gradient
- the impact angle
- the bulk heap apex shifting

Figure 6 depicts the parameter definition.

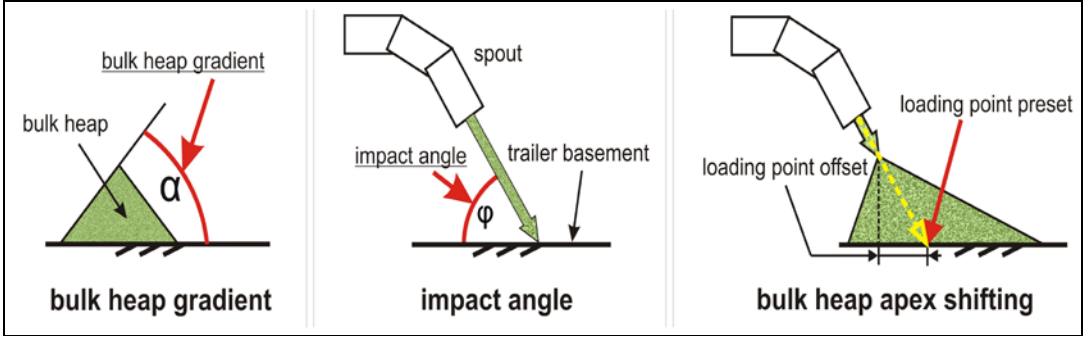

Figure 6: Bulk heap parameter definition

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.

3.3.2 Results and discussion

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 7, Figure 8 and Figure 9) depict some of the meaningful results of the grass harvesting period 2008 as well as the trend lines. The shown data is 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 7 derives the data and the trend lines for the front side as well as the back side gradient depending on 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. While 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.

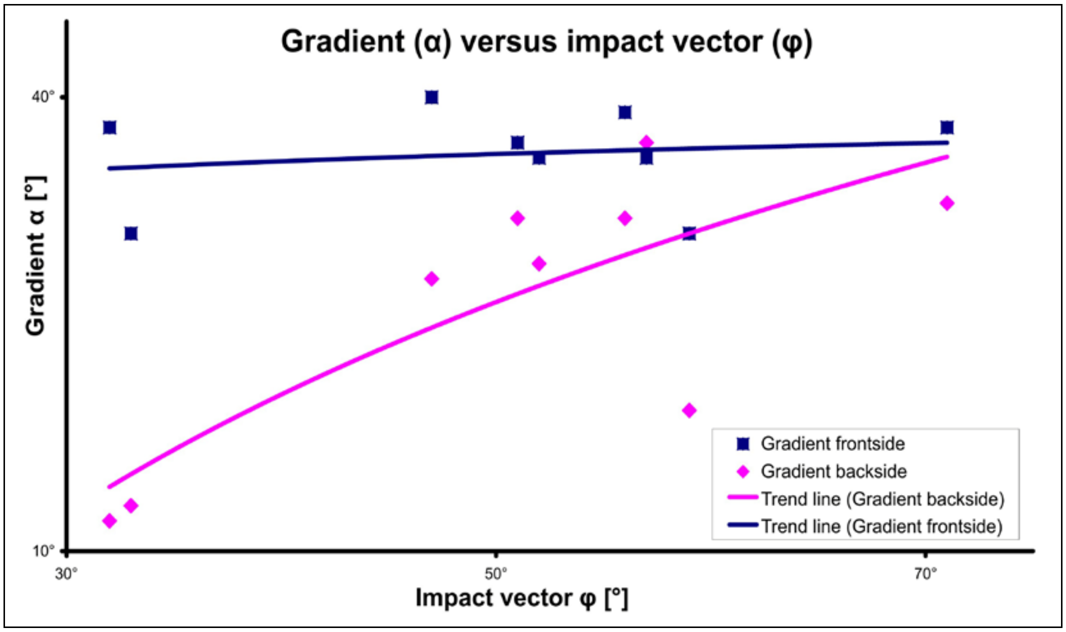

Figure 7: Bulk heap gradient versus impact vector

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 9 – the horizontal offset between the loading point and the impact point of the loading vector is increasing. Accordingly, whether the impact vector is relatively low, the most time of the loading process the crop stream only hits the slope of the bulk heap. In these cases the heaps grow contrary to the crop stream. One may presume that the gradient is increasing up to a saturated maximum level at about 39 degrees (cf. Figure 4, r). The results lead to another thesis: The lower the impact vector, the higher is the difference between the front side and the back side gradient. Figure 8 visualizes this relationship.

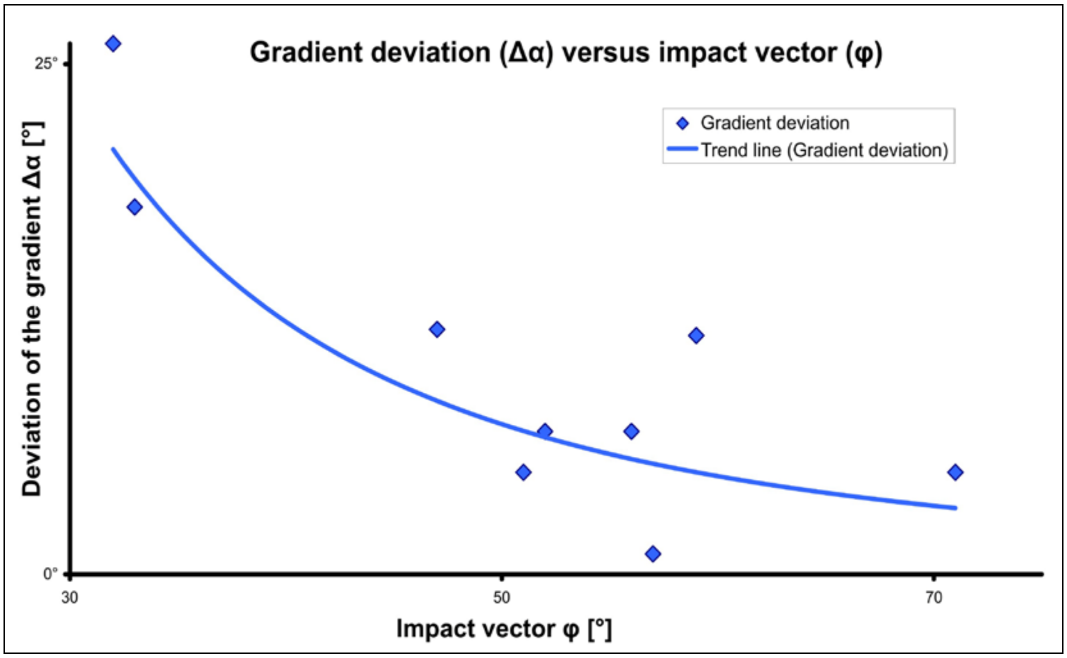

Figure 8: Gradient deviation versus impact vector

Figure 9 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.

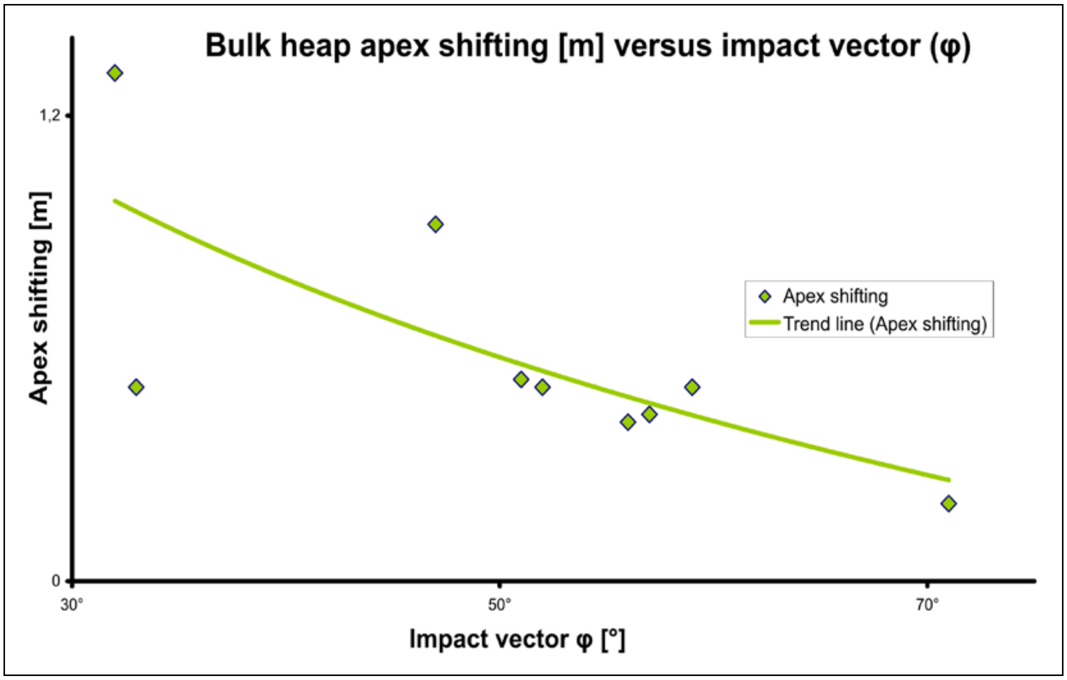

Figure 9: Bulk heap apex shifting versus impact vector

3.4 Modelling the loading process

Main task of this research project is the development of software models to describe bulk heaps of agricultural goods. Therefore exemplary heaps of silage crops – maize as well as grass – are examined in field trials as references. The all-important parameters which have to be implemented in the software model are the gradient at least in four orientations and the geometrical form of the bulk heaps. Modeling the form of bulk heaps via CFD and DEM techniques will not take place during the research. As Schulze (Schulze et al.) and Landry (Landry et al.) 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.

3.4.1 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 (cf. Figure 10). In field trails statistical data of single bulk heaps as well as interacting bulk heaps has been collected, regarding to the geometry and the description via mathematical functions.

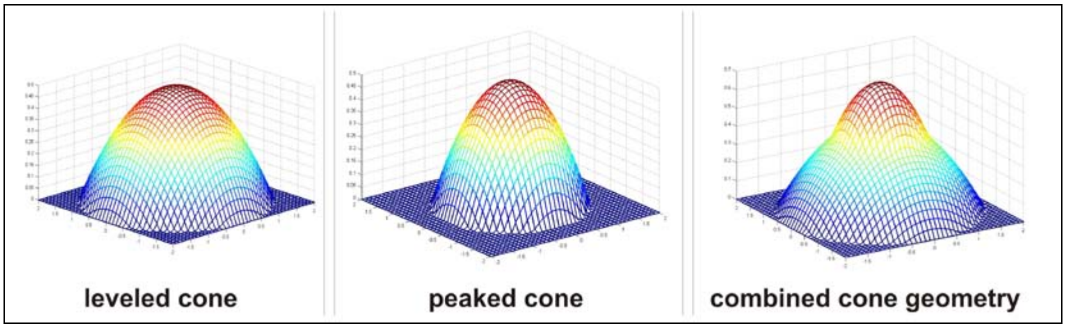

Figure 10: Exemplified combination of heap geometry

3.4.2 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.

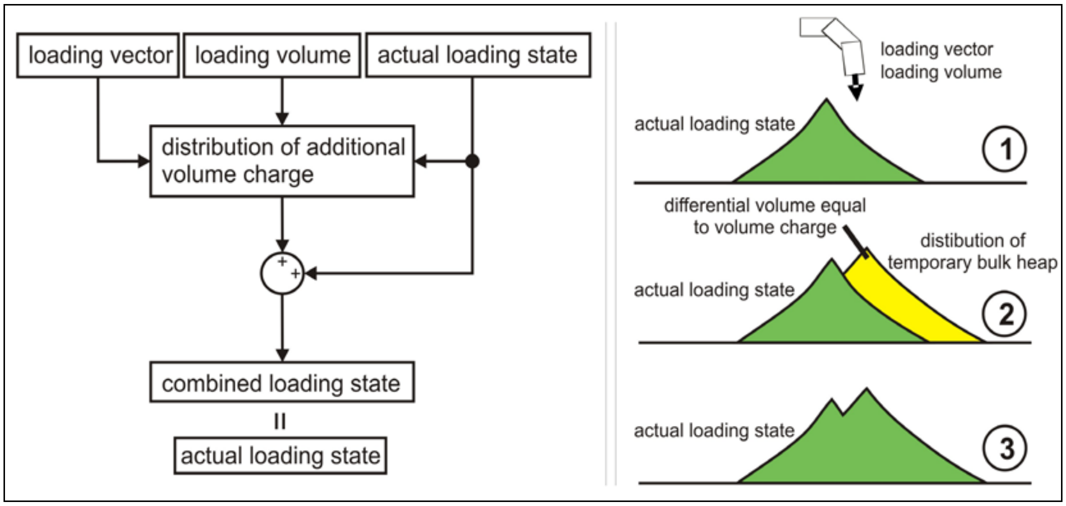

Figure 11: Software concept of the loading state definition

Considering the loading vector of the crop stream, a predefined discrete loading volume and especially the actual loading state, the distribution of the additional discrete loading volume is calculated (cf. Figure 11). The calculation of the distribution takes the bulk heap geometry model into account. The actual loading state as well as the distribution of the discrete additional volume is described via a surface in a 2D matrix. By adding the different matrices the updated actual loading state is defined. Thereby the calculated throughput (q.v. Section 2.1) is divided into predefined volume charges and virtually layered in the trailer space. Simultaneously the corresponding transportation unit is loaded in a similar way. At the current state field trials are made to compare and scrutinize mathematical bulk heap descriptions and the emerging load on the transportation unit.

4. 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 four years.
The consecutive investigation of the automation potential of the loading process implied the research on overloading strategies. 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 crop stream vector and bulk heap assembly have been analysed 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 loading models and loading strategies are implemented and evaluated with regards to the accuracy and the robustness.

4.1 Acknowledgments

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