Proceedings

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Commercial Vehicle Technology 2020/2021

Proceedings of the 6th Commercial Vehicle Technology Symposium

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Proceedings

Ein stetig steigender Fundus an Informationen ist heute notwendig, um die immer komplexer werdende Technik heutiger Kraftfahrzeuge zu verstehen. Funktionen, Arbeitsweise, Komponenten und Systeme entwickeln sich rasant. In immer schnelleren Zyklen verbreitet sich aktuelles Wissen gerade aus Konferenzen, Tagungen und Symposien in die Fachwelt. Den raschen Zugriff auf diese Informationen bietet diese Reihe Proceedings, die sich zur Aufgabe gestellt hat, das zum Verständnis topaktueller Technik rund um das Automobil erforderliche spezielle Wissen in der Systematik aus Konferenzen und Tagungen zusammen zu stellen und als Buch in Springer.com wie auch elektronisch in Springer Link und Springer Professional bereit zu stellen. Die Reihe wendet sich an Fahrzeug- und Motoreningenieure sowie Studierende, die aktuelles Fachwissen im Zusammenhang mit Fragestellungen ihres Arbeitsfeldes suchen. Professoren und Dozenten an Universitäten und Hochschulen mit Schwerpunkt Kraftfahrzeug- und Motorentechnik finden hier die Zusammenstellung von Veranstaltungen, die sie selber nicht besuchen konnten. Gutachtern, Forschern und Entwicklungsingenieuren in der Automobil- und Zulieferindustrie sowie Dienstleistern können die Proceedings wertvolle Antworten auf topaktuelle Fragen geben.

Today, a steadily growing store of information is called for in order to understand the increasingly complex technologies used in modern automobiles. Functions, modes of operation, components and systems are rapidly evolving, while at the same time the latest expertise is disseminated directly from conferences, congresses and symposia to the professional world in ever-faster cycles. This series of proceedings offers rapid access to this information, gathering the specific knowledge needed to keep up with cutting-edge advances in automotive technologies, employing the same systematic approach used at conferences and congresses and presenting it in print (available at Springer.com) and electronic (at Springer Link and Springer Professional) formats. The series addresses the needs of automotive engineers, motor design engineers and students looking for the latest expertise in connection with key questions in their field, while professors and instructors working in the areas of automotive and motor design engineering will also find summaries of industry events they weren't able to attend. The proceedings also offer valuable answers to the topical questions that concern assessors, researchers and developmental engineers in the automotive and supplier industry, as well as service providers.

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Preface

Unfortunately, unusual times require unusual measures ...

Since the COVID-19 pandemic still has a firm grip on us, we finally had to move our 6th Commercial Vehicle Technology Symposium to March 2021. However, the topics we have planned to present and discuss are still of a wide interest and therefore we decided to release the Proceedings in advance.

To guarantee a very high quality and a large impact, the program committee of the conference selected more than 50 very innovative contributions (talks and interactive poster presentations) out of all submitted papers. To ensure scientific innovation as well as practical benefit, at least 3 reviewers from academic and industry side evaluated each submitted paper and the best were selected for these proceedings.

The topics of the 6^{th} International Commercial Vehicle Technology Symposium again address different aspects of commercial vehicle development and production. Automated and connected driving and working is still subject of ongoing research. However, in parts, it is already applied in new products of the commercial vehicle industry, from which higher quality, more efficient workflows and an increase in the reliability and safety of the systems as well as cost savings are expected. Energy and resource efficiency, which is an evergreen because of the ambitious CO_2-reduction targets in the world, is addressed e.g. through the development of Efficient Driver Assistant Systems (EDAS) and tools to analyze the energy consumption within the vehicle including its auxiliary systems in detail. Alternative fuels and other innovations inside the drive train as well as special aspects of electromobility complement the efficiency topic. The latter is directly linked to safety and reliability issues as well as the usage variability and new design load targets due to different torque characteristic, weight distribution and driving behavior. General advances in commercial vehicle technologies and new simulation methods complete the program.

The 6^{th} CVT Symposium itself is planned for 9^{th} to 11^{th} March 2021 to continue a series of successful conferences, which took place every two years starting from 2010. Nearly all authors inside these proceedings have confirmed to hold their speech and give updates to their topics as the research and development continued besides corona. Therefore, we are confident, that we can continue our success story, if possible, with participants and speakers present, several vehicle demonstrators and numerous exhibitions from industry and research institutions. If a face-to-face event will not be possible, we are sure to find an interesting online format that will inspire you for participation. In any case, we will keep our international orientation and all German contributions will be simultaneously translated into English for our foreign guests. In addition, we will certainly have interesting guests from industry and politics, especially from the Ministry of Rhineland Palatinate, who will give their views to the future of commercial vehicle technology and business development.

Finally, we would like to take the opportunity to thank all people which were involved in completing the Symposium proceedings and will be involved in organizing the next years Symposium.

In addition, we would like to thank our gold sponsors

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for remaining loyal to us despite the corona pandemic and the double-postponement of the Symposium.

Furthermore, we would like to thank the university board and the government of Rhineland-Palatinate for their kind support in the past and hope that we can further built on it.

Stay confident!

Prof. Dr.-Ing. Roman Teutsch
Speaker of the Commercial Vehicle Alliance Kaiserslautern
Kaiserslautern, March 2020

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Automation of a Grid Connected Agricultural Swarm

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Link: http://www.gridcon-project.de/

Abstract. The growing interest for electrification in agriculture has led to projects such as GridCON [4] where a fully automated, all electric, cable powered tractor has been developed to address the limitations in operating hours found in battery electric tractors [1]. The GridCON2 [8] project follows up with the scaling of the cable technology to higher power levels to supply several tractors from a single energy source. Whereas the development of such machines is the focus of the field swarm project (Feldschwarm©) [5], the development of the cable carrying vehicle and the operation strategy for this grid connected swarm are scope of GridCON2.
The focus of this publication is the automation approach for this system where feasible field work plans are generated with respect to vehicle and swarm limitations. A hierarchical control structure executes and compensates for disturbances to keep to operation coordinated whilst being supervised by a remote operator.
The developments in electrification and automation of the GridCON projects are part of the journey towards a resource-saving, low-emission agriculture where the locally generated energy from agricultural enterprises (biogas, photovoltaic, wind etc.) can be directly and locally consumed.

Keywords: Automation, Swarm, Electrification, Agriculture, Tractor

1 Electrification and Grid Connection in Agriculture

Projects and products such as the John Deere SESAM Tractor [1], the Rigitrac SKE 50 Electric [2] and the Fendt e100 Vario [3] exemplify the interest in the area of electrification of agricultural machines. Developments such as [1] are driven by the goals of bringing performance, efficiency and environmental improvements to tractors. In order to provide the necessary energy for the electric drives, the mentioned projects employ batteries as the tractor's power supply. This solution allows both the direct consumption of locally generated energy in farms equipped with photovoltaic, wind and other renewable energy generation as well as CO_2 neutral and emission free operation in the field. The current state of battery technology, however, limits the operating hours of

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these vehicles making them unable to perform high power demanding tasks such as plowing or cultivating continuously for a full work day. Therefore, posing a major disadvantage to battery electric tractors with respect to their diesel-powered counterparts.

Within the publicly funded project GridCON [4] John Deere built a fully functional prototype demonstrating a new concept for powering agricultural machines. The GridCON Tractor (Fig. 1) is connected through a cable to a power source at the edge of the field, allowing unlimited continuous operating time, thus overcoming the limitations in energy density of state-of-the-art batteries while keeping the advantages of electrification. Through a high degree of automation, the prototype works the field while simultaneously handling the cable and following a pre-planned path. All the developed controls, such as cable tension, cable placement, implement actuation and path following have allowed the vehicle to perform field work without a driver.

Fig. 1. The all-electric, fully autonomous GridCON Tractor.

2 Grid Connected Swarm

The publicly funded Project Feldschwarm© [5] researches new machine concepts and their cooperative operation to form a swarm of vehicles that perform field work. Within this project John Deere focusses on the development of a fully electric swarm unit [6] ,[7] responsible exclusively for performing field work. The machine (Fig. 2) is powered externally and carries no energy supply of its own.

Fig. 2. The all-electric, fully automated swarm unit [6].

The underlaying vision pursued by John Deere is illustrated in Fig. 3 where the swarm unit can be seen as part of the concept for a fully electric and autonomous swarm of grid connected machines working the field together. The also publicly funded project GridCON2 [8] therefore deals with the scaling of the GridCON technology to higher power levels such that the cable transmitted energy can be distributed to supply power to several units. The result is the development of a dedicated Energy Distribution Vehicle capable of delivering power in the range of 1 MW through a cable (3-5 km). The defining characteristics of such a swarm are the task separation between field work done by the swarm unit, the supplying of power by the Energy Distribution Vehicle and the daisy-chaining of vehicles from the edge of the field up to the last machine.

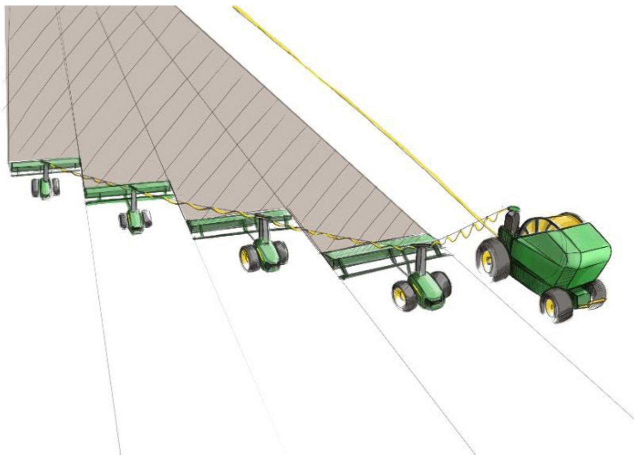

Fig. 3. Vision of an all-electric, fully automated field swarm [6].

The cable connection between infrastructure and the Energy Distribution Vehicle is handled similarly to the GridCON tractor by laying the cable besides the vehicle and subsequently collecting it as the field rows are worked upon, therefore imposing limitations to the driving patters that can be performed. The connection between vehicles however is achieved with a suspended cable solution with limited length, arrival and departure angles for the cables extending to and from the adjacent vehicles in the chain. These constraints lead to a coupling of the position, heading and speed of all swarm participants with respect to each other and the system's maneuverability. The automation solution that enables the potential productivity gains from the operation of such an agricultural production system is within the scope of the GridCON2 project and is the topic of this publication.

3 Goal and Approach

Given the system description, the goal is to define the means through which the grid connected swarm is controlled to complete field work tasks. The underlaying idea is to plan feasible trajectories for each swarm participant before-hand, execute the operation through a control structure able to adapt the plan with respect to disturbances in defined degrees of freedom and to remotely supervise and control the system.

The proposed approach (Fig. 4) results from the combination of aspects from three main areas. Firstly, the application of knowledge on the work to be done, machines involved and their respective actuators to plan trajectories stems from Computer Numerical Control (CNC) machines often used in manufacturing. In this context the set-point for each actuator on a machine is previously defined such that the result is dependent on each one being controlled within tolerance of its individual trajectory.

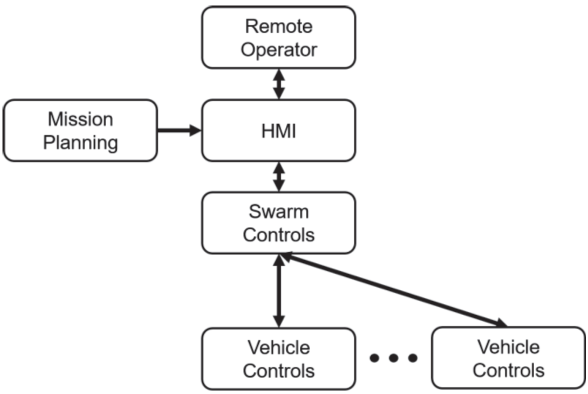

Fig. 4. Automation solution approach overview diagram.

Second are the conditions in agricultural environments. The exposure to weather and the soil variability result in significant disturbances to the navigation of agricultural machines. Furthermore, given the time windows for completion of different types of field work during a season, when a task is started on the field, much like for racing cars, disturbances must be mitigated, and the end of the task achieved. Unlike the operation of CNC machines, aborting the task is not an option.

Finally, the area of Supervisory Control and Data Acquisition (SCADA) systems orients not only the underlaying control architecture but also the Human-Machine Interface (HMI). In this factory automation context, the operator is tasked with monitoring the plant and being prepared to act in case of failures.

As automation expands and multiple machines come to work simultaneously in agriculture a paradigm shift arises in which the operator transitions from the role of vehicle driver to plant supervisor. The previously described system and guiding concepts are further elaborated in the following chapters outlining the automation of this novel fully automated and fully electric agricultural production system.

4 Mission Planning

The output of the planning stage can be summarized as a time series of swarm states. This encompasses the individual vehicle paths described as position and heading in addition to implement states such as height, speed or folding state depending on the implement being used. For the plan to be feasible, a series of constraints must be fulfilled with respect to vehicle dynamics, kinematics and their connections to other vehicles forming the swarm. The considered variables are presented in Table 1 and illustrated in Fig. 5.

Table 1. Path planning constraint variables.

Scope	Variable	Symbol	Constraint
Vehicle	Speed	v	$v_{min} < v < v_{max}$
Vehicle	Acceleration	$\dot{v}$	$\dot{v}_{min} < \dot{v} < \dot{v}_{max}$
Vehicle	Steering Angle	δ	$\delta_{min} < \delta < \delta_{max}$
Vehicle	Steering Angle Rate	$\dot{\delta}$	$\dot{\delta}_{min} < \dot{\delta} < \dot{\delta}_{max}$
Swarm	Departure Angle	α	$\alpha_{min} < \alpha < \alpha_{max}$
Swarm	Arrival Angle	β	$\beta_{min} < \beta < \beta_{max}$
Swarm	Relative Distance	l	$l_{min} < l < l_{max}$
Swarm	Relative Speed	$\dot{l}$	$\dot{l}_{min} < \dot{l} < \dot{l}_{max}$

The constrained derivatives included in Table 1 lead to continuous vehicle speed and steering angle, therefore limiting the peak power required from the vehicle actuators by avoiding the introduction of higher frequency components in the control loop that would be generated by discontinuous step commands. Additionally, this has the effect of also producing continuous relative distances, speeds, departure and arrival angles. In order to ensure the actual feasibility of the plan, the constraints for planning are chosen under the actual system limitations. The larger these margins are, the more the controls can recover from disturbances during operation.

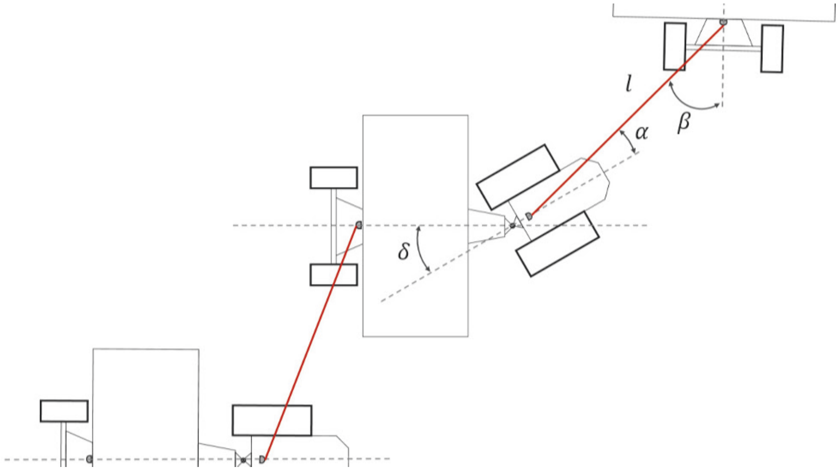

Fig. 5. Top view of the swarm with highlighted constraint variables for one unit.

The swarm's driving pattern is determined by the combination of the relationship between the number of swarm units and the number of rows to be worked in the field as well as the Energy Distribution Vehicle's driving pattern. The mission plan can then be generated where all constraints are fulfilled for a path that covers the whole field to be worked.

5 Control Structure

The execution of the planned mission is governed by a hierarchical control architecture with a human operator at the top interacting with the swarm control software which supervises the swarm units where each unit controls their actuators for navigation and field work. Due to the cable connection spanning all vehicles and infrastructure carrying not only means for power distribution but also communication, the control network is able to operate in real-time and synchronized through all the hierarchical levels. Through the definition of interfaces and hierarchization, a modular system structure is developed in order to decompose the overall task of automating the swarm into several elementary control problems.

5.1 Vehicle Controls

During swarm field work each vehicle follows its planned path, however in case of failure to comply to navigation constraints or for transport, the system may be required to perform individual manual maneuvers in order to be put back in a valid operating state. Therefore, each vehicle has its controls structured as a standalone machine that can be controlled directly by an operator or by an overlaying controller through the same interface. For manual control, direct access to vehicle speed and steering angle can be provided, where as for swarm operation the automated driving controllers are enabled. The mission plan is deployed into memory by the swarm software and can be updated at any time making the planning methodology independent from the control implementation.

In order to operate, each machine relies on a localization program for the ability to know its position. Through the combination of dead reckoning and Global Positioning System (GPS) sensors, each unit localizes itself in world coordinates and estimates wheel slip with an observer based on vehicle dynamics and driving kinematics. The automated operation is then governed by a set of main control loops. The first is responsible for the implement operation whereas navigation of the machine is separated into two. The approach is to let the steering actuation keep the vehicle driving along the planned path while the regulation of speed maintains the timing of the operation.

Lateral Tracking. The models and controls for the automated steering are developed with consideration for different steering geometries in order to minimize the lateral error for all swarm participants. The Energy Distribution Vehicle's driving kinematics are based on the Ackermann geometry. However, the satellite units not only employ an articulated steering system, but also have variable wheelbase that depends on the states of its implement, resulting in a dynamic driving geometry.

Preliminary tests (Fig. 6) with the swarm unit where performed to prove the concept of decoupling lateral and longitudinal tracking. By combining the known geometry and kinematics of the vehicle and the pure pursuit algorithm, the results from Fig. 7 were obtained and show an expected steady-state offset. Through sensor calibration to reduce steering angle and heading offsets in addition to tuning of the lookahead distance, a lesser lateral error can be achieved.

Fig. 6. Swarm Unit actively steering to perform field work with a pure pursuit based lateral path tracker during preliminary tests.

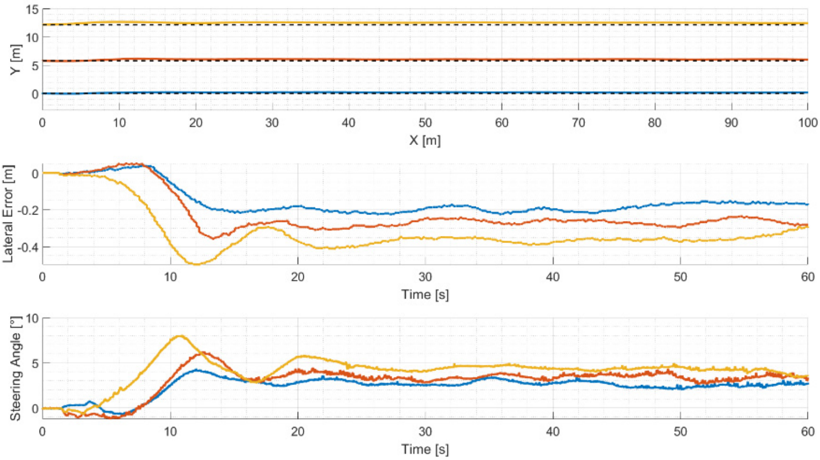

Fig. 7. Preliminary Swarm Unit lateral tracking results.

Longitudinal Tracking. In the context of a connected swarm, the longitudinal tracking of the path is a critical function since formation keeping and the synchronized execution is essential for maintaining the system within the boundaries constrains of the overhead cable connections. Certain types of field work, such as tillage, tend to require significant traction which, together with varying ground conditions, given the open-air nature of agricultural environments, lead to significant disturbances to navigation due to slipping wheels and power limitations. Therefore, additional correction is required besides the application of the pre-planned vehicle speed scaled by gear ratios and wheel radius as a feed-forward component to the drive train control.

Based on the wheel slip estimation from the localization program, the vehicle attempts to achieve the actual ground speed defined by its path. However, errors such as delay and inaccuracy on the wheel slip estimation and variations on the wheel radius lead to the accumulation of deviation with respect with the time plan of the swarm, therefore breaking its formation. To prevent this at the vehicle control level, a cascade control structure compares the current position of the machine along the path with the target position based on the mission's plan and adds a correction factor to the vehicle's reference speed to regulate the delay. The resulting effect is the proportional increasing and decreasing of the setpoint speed to maintain the vehicle on its position trajectory within the swarm's formation.

The delay compensation has its limitations, however. Attempting to compensate excessive wheel slip becomes counterproductive as the vehicle loses traction, furthermore, depending on soil characteristics when working the field, the limit in drive train power might not support the speeds required for the vehicle to regulate its delay. Therefore, the delay compensator is saturated during these conditions and signals this to the overlaying swarm controller.

5.2 Swarm Controls

The swarm control's main task is to act proactively to avoid that the swarm scope constraints from Table 1 are exceeded in order to continue the operation without interruption. During automated operation, the degree of freedom available for the swarm controller is time.

With the lateral controllers keeping the swarm participants along their paths, when one vehicle becomes excessively delayed, the swarm formation can be sustained by slowing down the other units to be equally delayed. Although increasing the time the overall mission takes to be completed, this allows the operation to be continued without interruption. The target system delay is then communicated to the individual delay regulators of each vehicle. The manipulation of this variable is not only influenced by excessive delay difference between vehicles but also the signals of wheel slip and power limit of each participant in the swarm to preemptively avoid excessive delay as these are the main contributing factors. With this mechanism the swarm controller actuates to allow the mission to diverge from the plan with respect to its time schedule in order to keep the formation of the relative poses of the vehicles.

In addition to this, manual actuation of the swarm is supported through the assisted driving of individual machines. When necessary, this mode allows the operator to individually drive each vehicle while the swarm scope constraints from Table 1 are monitored. As they approach their limits, manual control commands are proportionally attenuated, and this is brought to the attention of the operator through warning and alarm signals before the interruption of the operation in case of constraints being exceeded.

6 Operation Strategy

Operation of standard tractors in agriculture is well known, especially with respect to navigation. As automation takes over more tasks in that area, less input is required for a person to drive the vehicles. Furthermore, with the increased complexity of systems such as the GridCON tractor, automation becomes a necessity, as the concurrent operation required for driving the vehicle and managing the cable would impose an undesirable amount of load on the operator. A grid connected swarm system then, with all the required automation to sustain its activities, will require a set of inputs largely different from what would be required from a driver utilizing a standard tractor.

The task of the operator is then to manage the mission planning, activate the automated operation and remotely supervise the swarm during field work in order to be ready to act in case of failures, much like a plant supervisor in an automated factory. This is possible with the high bandwidth communication available through the cable connection since all vehicle sensor data and video streams from onboard cameras can be made available remotely in real-time.

Given the large amount of data available to the operator, the user-interface must prioritize and organize the data such that it is meaningful and manageable by a person. The key aspect of formation keeping, for instance, is one whose status should be easily accessible. The concept is to make this information available through graphical display, rather than a list of numbers, by combining 3 dimensional (3D) models of the vehicles and the field with the live data from the control system. The result is a virtual environment that replicates the state of the swarm, the vehicles and the operation through real-time animation (Fig. 8). The creation of a virtual environment serves not only as a tool during the operation of the system, but also for mission planning, since the visualization can be used to evaluate the mission plan beforehand. These are then complemented by visual elements that show detailed information as well as warnings from the control system. Such a display of information combined with video feeds from the units provides the information as well as the situational awareness required for the operator to supervise the swarm.

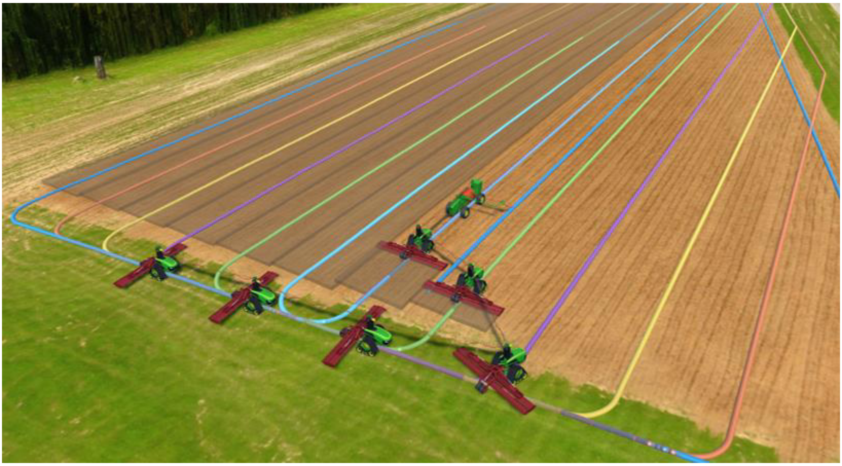

Fig. 8. Visualization of the grid connected swarm in the virtual environment.

During automated operation, the user-interface allows the operator the stablish the mission plan, deploy the swarm and supervise it. Additionally, it provides the means for use of the assisted manual control of the individual units to account for exceptional maneuvering in the case of failures or navigation in constrained spaces. Different input methods can be utilized, such as joysticks and touch-screens, as exemplified in Fig. 9. By communicating through the swarm controller, the swarm constraints are still monitored and limit the manual operation to keep them fulfilled.

Fig. 9. User interface prototype displaying real-time data from the control system and touch-screen oriented control elements.

7 Conclusion and Further Work

The developments in electric power distribution from the GridCON project enable further research into electrification and automation in agriculture despite the limitations of state-of-the-art batteries. By scaling that solution to higher power levels in GridCON2, a paradigm shifting agricultural production system is envisioned. The cooperative field work of several cable powered machines brings a large potential for productivity increase due to the simultaneous and theoretically unlimited operating time. The challenges faced in the required automation to bring the highly productive, fully electric grid connected swarm vision to reality were assessed in this publication and a solution approach has been presented.

The limitations of not only each individual machine but also from the system, are considered by defining mission plans that are checked for those constraints before being deployed. The resulting trajectories are therefore known beforehand to be feasible within certain margins left for disturbance compensation and provide data for feedforward components in the underlaying controls.

The planned paths are initially executed by each unit independently from each other, as each vehicle operates it's steering and drive train to follow its own plan. These tasks are separated and decomposed into elementary control tasks for lateral and longitudinal path tracking. Firstly, the automated steering, which has been shown in preliminary test to be able to keep the swarm unit laterally bound to its path despite the characteristics of its driving kinematics when performing field work. And secondly the cascade control structure defined for delay compensation with the underlaying observer-based ground speed compensation.

By gathering data from all machines, the swarm controller can monitor and act proactively with respect to the coordination and constraints of the system. Formation keeping is then prioritized by manipulating the target delay of the entire operation when participants are not able to compensate for their longitudinal tracking error. This strategy allows the swarm to operate in the agricultural context where environmental conditions can generate significative disturbances to navigation, such as wheel slip, that may not be able to be compensated entirely.

The link starting at the power supply infrastructure and ending at the last vehicle not only carries the means for the distribution of power but also for communication. It creates a synchronized real-time control network enabling not only the described control strategy but the teleoperation and remote supervision of the swarm. Through this networking, all relevant inputs and outputs from the distributed controls are made available remotely. Supervision is supported by a 3D visualization in a virtual environment combined with video streams to provide situational awareness to the operator. Additionally, the user interface enables assisted manual control of the swarm and its individual participants.

The outlined architecture, including the previously described operation concept, functions and controls, combined with the Energy Distribution Vehicle, satellite units and their connections, results in a novel automated fully electric agricultural production system where a group of machines cooperatively navigates and executes field work. Though preliminary tests with lateral tracking and user-interfaces have been successfully realized, the presented approach is still to be tested with the full system as all components become available.

The developments in electrification combined with the GridCON technology provide new possibilities for the future of productivity focused highly automated agricultural production systems. Through these developments John Deere explores new systems where energy can be used more effectively by allowing direct connection to local farm infrastructure therefore taking advantage of locally generated power. Furthermore, through these locally emission-free and CO_2 neutral machines further steps are taken in the direction of a green future for agriculture.

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Requirements of Automated Vehicles and Depots for the Initial Step of Automated Public Transport

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Abstract. In recent years, the development of Advanced Driver Assistance Systems (ADAS) has progressed rapidly. In order to make use of the advantages of self-driving busses, it is necessary to prepare the bus depots for automated vehicles. The aim of this paper is to investigate the associated optimization potential, to use it to raise the attention to the necessity of automated depots and to underline the profitability of a fully automated depot. In addition, automated driving on public roads is not feasible without restrictions, due to the legal framework in Europe. However, these regulations do not apply within cordoned off areas, as they are private property. Therefore terminals and depots offer already the possibility for test fields.
Accordingly, and for initiating the preparation of depots, this paper first presents the state of the art of self-driving passenger cars, followed by automated busses. Subsequently the current operational tasks of a selected exemplary depot in Munich is recorded. For the creation of a concept for automated depots several requirements are presented. These include not only the technical requirements for the bus fleet and the Depot Operating System (DOS), but also demands on the infrastructure, the communication interface and the legal framework. Subsequently, a gap analysis is made by comparing the requirements and the state of the art.

Keywords: Automated Commercial Vehicles, Automated Busses, Public Transportation Depots, Depot Operational Processes

1 Motivation for Depot Automation

It is expected that new ADAS will offer the possibility of increasing safety on public roads. Additionally the raising traffic volume, as well as a lack of qualified drivers, makes the exploiting of opportunities arising with self-driving busses more important. In addition, driver-less busses offer a significant influence on

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economic efficiency [12]. Due to technological progress and adoption of the legal framework, it is expected that automated vehicles will be able to travel on public roads within the next decades [7].

As long as automated driving is only permitted with explicit exemption, other possibilities for test fields need to be established. Restricted areas offer the possibility of testing the behavior of automated vehicles under controllable conditions, without violating the legal regulations. In order to ensure transferability to public roads the control systems should be adapted to the road traffic regulations. However, closed-off areas such as depots and terminals also pose further challenges to be considered. Therefore the state of the art of automated vehicles and fleet management on depots has to be determined. Followed by a gap analysis, which constitutes the basis for a technical road map. This road map indicates the necessity for preparation the automation of depots.

2 State of the Art for Automated Driving

The main technological background for automated passenger cars and commercial vehicles are the same. For this reason, the following section first presents driver-less driving in general and subsequently discusses the challenges for self-driving busses in particular.

2.1 Automated Driving

Technological improvement and volume production allow the integration of more sensors into vehicles and calculation of traffic scenarios in real-time. As a result, the number of Advanced Driver Assistance Systems (ADAS) has increased considerably. Figure 1 gives an overview about the built-in sensors and exemplary associated ADAS. In addition to ultrasonic sensors, short range radar and long range radar, lidar and optical sensors can be found in one single vehicle. For example mainly radar and camera were used for the 123 km long drive "Mercedes-Benz S500 Intelligent-Drive" from Mannheim to Pforzheim, Germany [15]. The information of these sensors are fused and processed by the logic on board. Through these sensors the vehicle is able to detect its environment.

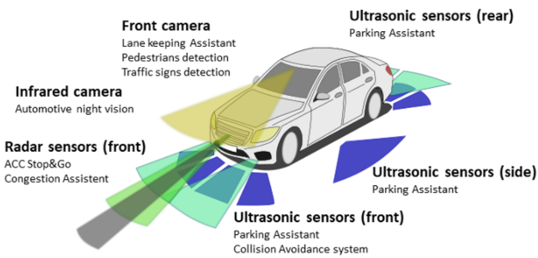

Fig. 1: Exemplary selected built-in sensors and the connected ADAS

For reaction to the perceived sensor data two possible implementations exist. On the one hand the realization can be done by classical implementation of controller code. The composition of the controller and the system is only possible if the physical process to be controlled is completely known [5]. However, in case of self-driving vehicles the physical process and dynamic behavior is different for each vehicle model. To take any variable into account while designing an implementation for a vehicle using the classical approach involves too much effort. Despite, a not inconsiderable number of market available ADAS have already been successfully implemented through this approach, such as adaptive cruise control, automatic breaking and lane keeping assistance.

On the other hand the Artificial Intelligence (AI) approach builds millions connections between information obtained by the sensors (input) and the dynamic behavior (output), considering the vehicle as a black box. This approach is used to solve an existing high level problem which cannot be easily solved with classical programming. Machine Learning, as a part of AI, enables the implementation of a system by learning an algorithm on its own [14]. This procedure makes problems solvable, which would pose challenges using the classical approach. After all, the use of a black box makes troubleshooting and maintenance more complicated. As a result, the most reasonable solution is, the approaches are not mutually exclusive. It is appropriate to combine classical low level control and AI high-level reasoning to support decision making [5], as shown in Figure 2.

2.2 Automated Busses

The progress in case of commercial vehicles in particular will offer the possibility to increase safety on public roads, save energy and reduce personal costs. In case of self-driving busses, on-board components are responsible for receiving and fusing the sensor data and calculating the trajectory planning. This also includes the interpretation according to the scene recognition by the AI., but also the tasks of the classical approach such as dynamic control or steering. In addition an update of the route has to be possible. Furthermore there is a need for a report in case of a defect on the bus, since there is no driver present for this purpose. This leads to a necessity of a remote support for the fleet management, which is shown in Figure 2. Due to the expected high amount of automated shuttles, the complexity increases at a level that a centralized approach becomes infeasible [5].

As described in Section 2.1, a combination of AI and the classical approach for modeling is suitable for solving the problem of automated driving. Figure 2 illustrates which tasks are performed by the AI and which by classical implementation in case of an self-driving bus. Additionally, it shows the necessary interface to the environment. This includes next to the communication with the remote support, also a selection of built-in sensors. Vehicles are equipped with a large number of those sensors in order to realize a monitoring of the entire area around the vehicle (360 deg) at all time.