FELDSCHWARM[1]-UI:

A User Interface for Controlling Swarm Technology

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1. Abstract

Facing the growing shortage of skilled workers and the demand for more effective processes, the increasing digital penetration of agricultural systems is heading to full automation. Within just a few years, they will be able to complete basic tasks in the field on their own. The project Feldschwarm promotes the development of autonomous agricultural machinery. It focuses on medium-sized vehicles, which can multiply their working width in formations or combine different processing steps as needed. The management of such machine swarms means new requirements and use operation scenarios, which lead to different Human Machine Interfaces (HMI).

This paper describes both systematically and by example, how the transition from direct machine operation to adaptive management systems can be achieved. It discusses the integration of assistive functionalities as well as approaches for adaptive and scalable systems, multimodal interaction and the consideration of bidirectional learning mechanisms taken in to account in the "Feldschwarm-User Interface(UI). It integrates various scopes from individual machine perspective (in case of emergency or special tasks) and swarm perspective in management mode. The operating concept not only supports cabin-based use cases but also monitoring and operation from the field or on the move. The developed operation concept extend the capabilities of elaborated vehicle based HMIs to fit the needs of tomorrows increasingly automated fleets and agricultural processes.

2. Current state and Outlook in machine operation in the agricultural sector

It is known that agricultural technology faces radical changes. An increasing demand for agricultural products (United Nations, 2015) (Amrhein-Bläser, 2013), meets productivity limitations through physical limits of machine size, processing speed and payloads as well as a vanish of qualified employees (Krzywinski, 2017). On the one hand, the deeper penetration of the systems and processes leads to a better and more granular knowledge and therefore

[1] Feldschwarm is a registered word mark (DPMA registration number 302013018880) of the Fraunhofer Gesellschaft

creates the basis for the development of new assistance systems (Schmidt, 2018). On the other hand, the digitization of systems also allows extensive interventions in the machine-bound process parameters, if the necessary information and setting options are available (Deter, 2017). Both lead to a considerable increase in complexity of operating agricultural machinery such as tractors or combine harvesters. This is also effected by the increasing integration of farm management systems and precision farming applications that collect, process and integrate data into the operating systems in real time (365Farmnet, 2019). Thus, the focus of machine operators is shifting from direct machine control to management tasks. Cabin workspaces are equipped with more displays (Fendt, 2019), more linked systems as well as extensible and integrative solutions as shown in the “Smart Cab” (CABConceptCluster, 2017) becoming more important.

On this ground, the automation of processes and machines seems to provide potential increase in safety, performance and flexibility of fieldwork even more. Autonomous machines allow the operation of more and smaller machines, combined in so-called swarms so increase flexibility (Krzywinski, 2017).

The Feldschwarm-project aims on the development of a hybrid powered tool platform for soil cultivation. These platform modules are able to carry different tools and autonomously drive along calculated routes on the field. Figure 1 shows a tillage scenario, performed by three autonomous drones. Besides the technology for positioning, object recognition and system controls is quite advanced, mechanical failures and unidentified obstacles still inevitably lead to a machine stop, which makes human interventions necessary.

Fig.1: Modular concept of the Feldschwarm units

3. Challenges & Requirements for HMI in Agricultural Technology

A substantial increase of productivity could only be reached by improving the human-machine-cooperation (Geisberger & Broy). As described, the transition to fully autonomous machines leads to even more complex assistance systems. It also expands the range of tasks by monitoring and diagnostics. To keep these as simple as possible, transparent systems (providing all the necessary information to diagnose operating status) and predictable machine/system behaviour are required. The rapid development of these systems will result in machines being continuously supplied with software updates and feature enhancements over their lifetime. Therefore new knowledge about processes and functions has to be imparted constantly. The initial setup of assistance systems will become major part of machine operation. Aiming for optimizing human-machine cooperation, it is also important to consider individual skills and needs of the operators. Performance, motivation, sense of responsibility and process knowledge differ considerably between the employment profiles.

When switching between management and single machine operation in cases of danger or malfunctions, it is going to be challenging to connect the operator to the situation as fast as possible. Wide spread tasks also makes it difficult to create a balanced work process in terms of stress and task monotony. Figure 2 shows that over- or underloading the operator with too many or too few tasks should be avoided to ensure sustainable safe and more comfortable operation. Adaptive User Interfaces of the future can help to keep the balance, by providing specific assistance functions, knowledge or tasks in certain situations.

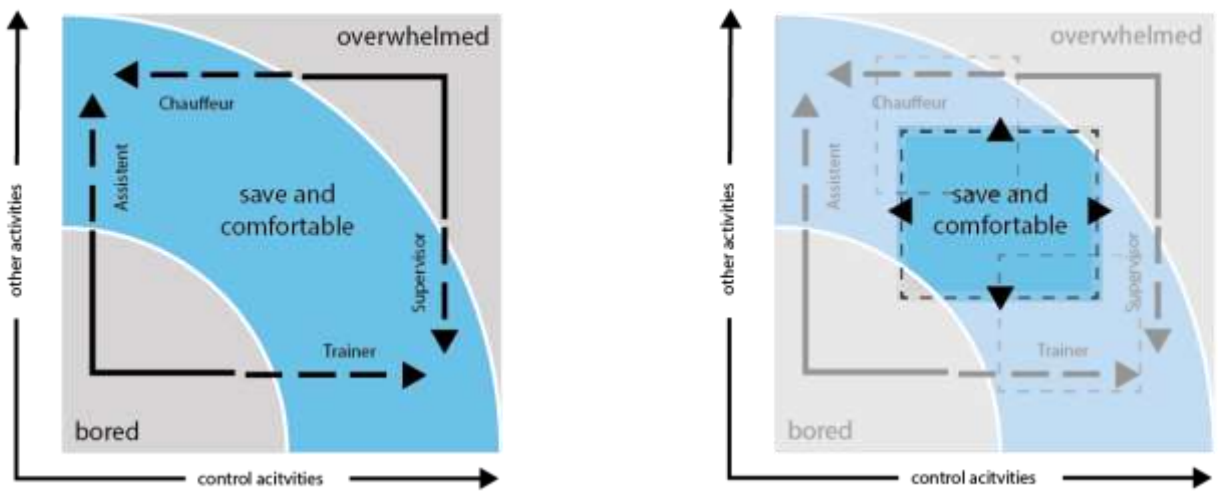

Fig.2: Using HMI to framing work processes by providing specific assistance functions, knowledge or tasks

With the shift of being responsible not for just one but many machines, the question of the localization of the operating environment is also set new. In some scenarios, a vehicle cabin still provides the optimal control station, but others emphasize the monitoring from the field or from external control panels. The opening for different platforms and the integration of mobile devices such as tablets, smartphones or other wearables, represents a key to unlocking the potential of automation and connected machinery on the field.

4. Facing the Challenges – with a holistic HMI-Approach

The question of how the future working environments enable machine operators to supervise and control a network of electrified machines in a reliable, safe and healthy way may be answered by intelligent human machine interfaces (Grote, Ryser, Wäfler, Windischer, & Weik, 2000). User-Centred Design (UCD) puts the operator in the focus of product development. Besides our experience-integrated design approach for accessing all of the human aspects (social, emotional, cognitive and anthropometric), we take into account the particularities, requirements and changes of the specific machine applications and technologies. Regarding the challenges mentioned above and based on screening the latest trends and R&D efforts on the market we identified six topics that are important for future HMI in professional (industrial) applications: assistance, adaptivity, learning, scalability, multimodality and work experience (as shown in Fig.3). The systematology illustrates conceptual and technical approaches for the interaction design and emphasizes the combination of these.

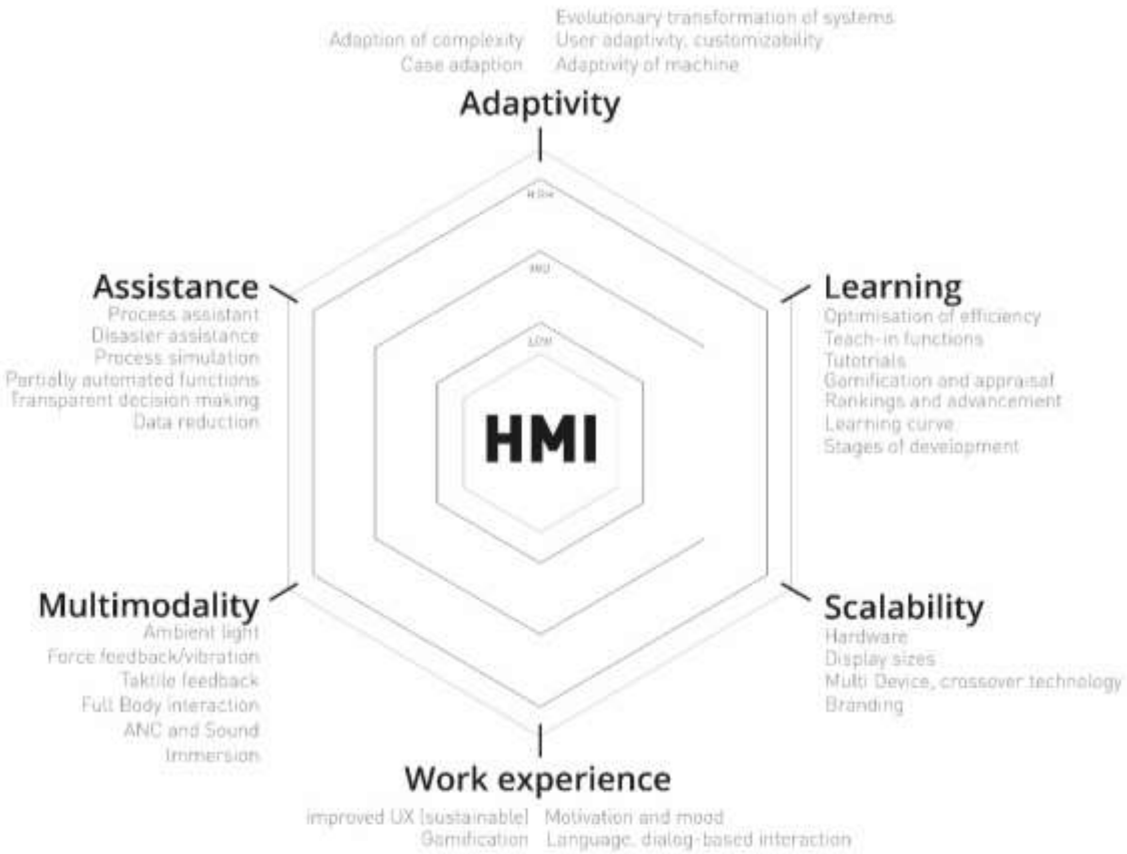

Fig.3: Systematics for crucial HMI topics for industrial applications

The topics are characterized as follows:

Adaptivity: In agriculture, display-based interfaces are already widely used nowadays. These allow a great variability in the arrangement, size and behaviour of information. Combined with various sensors (e.g. environment detection, operator tracking), the content can be adapted to tasks, situations (e.g. normal operation vs. dangerous situation) and operators (e.g. Beginner vs. professional) to support individual workflows and reduce the complexity and information density following the principle to provide the right information, at the right time in the right place.

Assistance: Most agricultural machines are already equipped with assistance systems and will support the operator even more in the future. For the HMI, this means that complex, often situation-specific information and features have to be delivered in the right way and in the right place. If work process-relevant or even safety-critical functions are connected to the assistance functions, the placement of the operating status of the assistance systems (hardware and software) is crucial. In addition, some assistance functions must be set up or adapted to specific conditions.

Learning-Capabilities: On the one hand, the intelligent systems of the future only need to be "taught" certain subtasks in order to be able to execute them autonomously. On the other hand, the systems will most likely contain a deeper and broader process understanding than the operators who move further and further away from the actual work process. At this point, the system can provide the user with process knowledge and strategies to support them, especially in long-term developments.

Scalability: As the processes become more flexible and the costs of HMI developments increase, systems need to be designed to run on different hardware platforms, to cover different tools or even vehicles. The Expandability with customer- and supplier-specific add-on solutions and open-source content will also play an increasing role.

Multimodality: In the field of HCI (Human Computer Interaction) and tactile Internet (5G), the inclusion of multiple channels of perception for optimized provision of information has been discussed and practiced for some time. In response to the restrictive interaction with touch-display-based graphical interfaces, multimodal operating environments provide better cognitive processing and information categorization to capture complex information flows faster and more securely. Interactive technologies such as ambient light, active noise cancelling, adaptive physical controls, vibration feedback, provide a rich set of interaction design and information coding.

Work experience: If performance and efficiency continue to be optimized, the consideration of user needs plays an increasingly important role. Understanding and empowering natural needs, such as autonomy, security, competence, and importance, play an important role in creating inspirational and psychologically supportive operating environments. In particular, (pseudo) social interactions have a large influence on these (Burmester & Zeiner, 2018) (Wölfel & Krzywinski, 2019).

We use the classification shown in Figure 3 as a guide to a holistic approach to the topic of HMI and the linking to the user and application requirements, technical possibilities and operating functions. We categorize approaches, entire interaction concepts and technologies in the respective categories in 5 stages (1: no influence, 2:low - already on the market, 3:mid - already on the market, but not in this industry, 4: high - new, 5: visionary).

5. FELDSCHWARM UI Concept:

The Feldschwarm incorporate the operator as an important part of the system and use his or her characteristics for improving productivity. Based on the operating paradigms of familiar terminal interfaces and logistics management applications, the Feldschwarm-HMI merges both to provide a mobile swarm control panel for autonomous agricultural machines. Specifically, the developed HMI allows the control and monitoring of several autonomous drones that can be equipped with various tillage tools (e.g. cultivators, rollers, harrows, ...) and can perform the conventional tasks on their own. As a result, one aspect will be the focus of the operator: What is the system doing right now, what will the system do next? The user interface has to provide a clear and reduced to the essential answer to these questions at all times. The grouping of vehicle data with different tools and tasks poses particular challenges to easy-to-understand but comprehensive information mapping. A consistent basic structure supports the understanding and perception of the operator. Accordingly, the user interface is divided into an upper-status bar, a menu bar with integrated status icons and a collapsible information window next to an interactive map with a timeline. The touch display UI, which is enhanced by physical controls, allows both operations from a vehicle cabin (for example tractor) and the field or the edge of the field. It combines the flexibility of a touch-display-based interaction with the operational security of physical controls, as shown in Figure 3.

Fig.3: Prototype of the Feldschwarm User Interface and its profile in our HMI-Systematics

Adaptivity: Various working modes allow switching between the interaction of individual machines, for example for maintenance or monitoring tasks, and the control of overall processes. The main focus can be changed step by step from the single-vehicle (Figure 4, left), through the swarm of one field (Figure 4, right) to the overview of all managed units and tools. According to the selected monitoring level, the representations of the user interface adapt to the required depth of information. For example, the level of detail of information mapping and all illustrations is graded from simple to complex. Furthermore, certain aspects such as trajectory planning and course classification of individual machines are only visible when needed. The different levels of abstraction ensure the right degree of clarity and information content, depending on the situation. Menu bar, information window as well as map and timeline form a unit and set system messages in a temporal, local and consequences reflecting relationship. Finally, the operator should quickly gain an impression of when and where action is needed. The change between the levels can be done continuously via the interactive map or via selection in the menu. Besides, each vehicle can be manually controlled in the implemented remote control mode (Figure 5, right), for example for maneuvering tasks. However, the operator must be in the close proximity of the vehicle and has to identify the machine via RFID technology.

The Feldschwarm-UI is prepared for user profiles with various user roles. Thus, the works manager can focus on the internal, cross-field processes, while swarm technicians or field operators have a deeper access to the machine level.

Fig.4: Swarm management at the machine level (left) and field level (right)

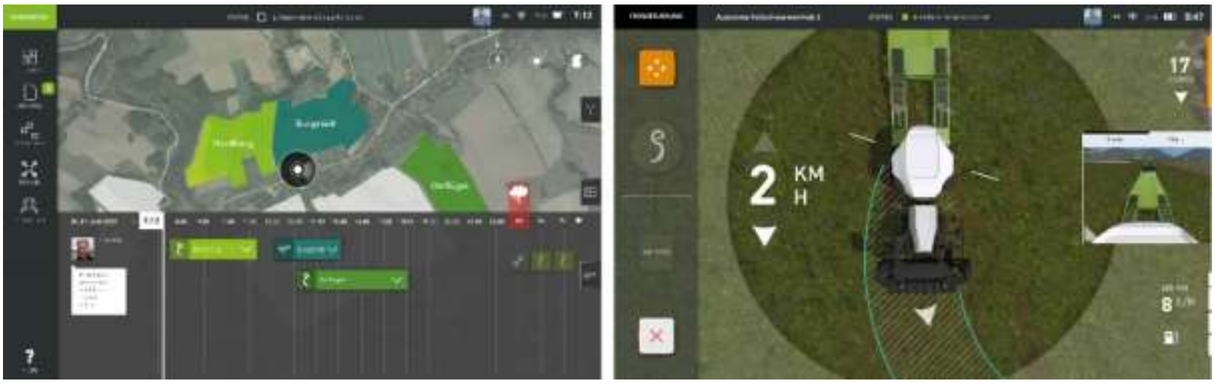

Fig.5: Integrated schedule (left) and teleoperation mode for single-machine (right)

Assistance: The core point of the support of the work process by the system is the prioritized and clear provision of the relevant vehicle data such as position, operating status (in particular of the automated functions and systems), speed and upcoming work steps. Only then, it is possible for the operator to monitor several vehicles and to ensure the maintenance of the overall process. Furthermore, various warning assistants and assistance functions are integrated, which support the operator in exceptional situations, where obstacles are detected or the machine and tool could be damaged. An exemplary scenario: the field swarm recognizes an obstacle (for example stones, mud holes, game) in an upcoming lane and gives a preventive message to the operator, who has the possibility of personal or system-assisted risk assessment. In addition, he is able to decide directly how the machine should react to this obstacle (driving around, stopping). The system distinguishes according to different levels of urgency and criticality, which is reflected in the way in which the instructions are presented. The programming of the routes and the vehicle allocation as well as the tool management are not carried out by the operator.

Learning: The presentation of process parameters with trend information gives the operator immediate feedback on the effects of his actions. This allows even complex dependencies to be detected visually quickly. At this point, an overall understanding is less strongly promoted, but the iterative adjustment succeeds much faster.

Scalability: The developed and tested system does not yet consider any hardware specifications. The concept itself is compatible with all touch displays that provide a resolution of at least 1280x720 pixels and a diagonal of at least 10 ". We are also working to adapt the system to a smartphone and/or a smartwatch as an option to get more flexibility.

Multimodality: The concept aims to be flexible, the inclusion of physical controls or complementary visual and acoustic media is less extensive. Physical controls make it easy to control the machine, navigate the system, and set parameters along with differentiated vibratory feedback. The coupling with light signals on the vehicles gives the operator a reassurance about the accuracy of the data presented to him in the display interface.

6. Outlook

With increasing digitization, agriculture continues the transformation into a complex logistics network in which people communicate intensively with several machines and machines exchange data by themselves. The Feldschwarm-UI faces the increasing demands for accuracy and speed of work, along with the complexity of information, with differentiated managing and operating modes to freely scale the interface between process management and single machine operation or monitoring. A consistent interaction and graphic design supports seamless switching between these two. It extends elaborated single-vehicle based HMIs with new functionalities and process visualizations. The Operators can use individualized user-profiles and an adaptive Interface that reflect his individual workflows, work tasks and environment. This makes work with automated machinery on the field more effective and safe. We consider automated swarms will have a deep impact on the agricultural work processes. With the connection of management and operation, the Feldschwarm-UI proposes an intuitive and reduced approach to remain control on the field. The presented UI is set up as an interactive web-based Application with open interfaces like mQTT, for now. Its visualizations and control functions are connected with the "Farming Simulator" and thereby provides a highly interactive and realistic base for evaluation.

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