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Design Recommendations for an Adaptive Control System in Agricultural Tractors Based on Expert Knowledge

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ABSTRACT

Due to various implements in agricultural technology, the human-machine interface (HMI) in tractors is required to cover a wide range of different operating scenarios. This contribution describes the methodical procedure for the development of design recommendations for an adaptive interface system in agricultural tractors. The requirements for an adaptive operating armrest are achieved by the detailed analysis of the operating scenarios, the operating characteristics, the investigation of the compatibilities, and the consideration of the operation types. The results lead to design recommendations for a conceptual design of the adaptive HMI for the control functions of the investigated implements.

Keywords: Usability, User interfaces, Human machine interaction, Adaptive control elements, User experience

INTRODUCTION

Due to various implements in agricultural technology, the human machine interface (HMI) in tractors is required to cover a wide range of different operating scenarios (ISO 12934, 2021). In order to cover the wide range of functionalities the current trend towards an increasing usage of virtual user interfaces via touchscreens is also visible in the field of agricultural technology. The so-called universal terminals (UT) offer all the advantages of graphical user interfaces, such as high flexibility and information density. However, all haptic information is lost, which is necessary for blind operation or proportional operation. According to the current state of the art, HMIs in agricultural tractors are based on a compromise consisting of one or more UTs and a high number of static control elements. The wide range of operating scenarios and changing operating characteristics can be covered only suboptimally by static control elements on the operating armrest and lead to a complex and unclear operating situation, which results in a bad usability for the user. (Kaufman et al. 2020; Schmid, 2017) An optimized solution with intuitive operation, high usability and the avoidance of operating errors requires an HMI that can adapt optimally to changing scenarios. Based on the previous research project aISA, the current project aISA 2.0 (adaptive interface systems in agricultural tractors) focuses on the development of an adaptive operating system in order to provide an optimal interface for the various and changing operating scenarios in tractors. Based on a methodical categorization, a design recommendation for the interface system is developed, among others considering availability, positioning, actuation type and interface technology of the functions examined. For this purpose, expert knowledge and a method for analyzing functionalities and operating is used. The existing method (Kaufman et al. 2020) will be evolved and applied to agricultural implements.

METHOD

This chapter describes the methodical approach to develop a design recommendation for an adaptive control system in agricultural tractors. An expert survey was created and conducted to provide a data basis for the analysis. The survey is described in detail in the following section and serves as information input for the subsequent function and operation analysis, short: FOA. The FOA ultimately results in design recommendations for the adaptive control elements and design recommendations for the position and arrangement of the control elements as well as the relationship between real and virtual control elements in the overall interface system.

Expert Interviews

This paper focuses on various agricultural implements that can be coupled to tractors. These implements possess various functionalities, which require to be represented by the HMI in the tractor. In order to gather information on the different implements and their functions, a questionnaire for an expert interview was created and a preselection of the implements to be investigated was made. The objective was to gather every relevant control function and having each function evaluated by the expert in terms of different aspects. General settings, menu navigation and indicators not related to active controls were excluded.

The expert interviews were conducted with developers from six different implement manufacturers (Bergmann, Rauch, Krone, Lemken, Zunhammer and Grimme) regarding 12 different implements. On average, each interview lasted 1.5 - 2 hours. The following list includes the examined implements: From the company Bergmann the loader wagon, universal spreader and transfer trailer were examined. Together with manufacturer Rauch, the functions of the pneumatic fertilizer spreader and two-disc fertilizer spreader were investigated. With the company Krone, four-rotor rake, round baler and combination baler and wrapper were examined. Furthermore, the seed drill and precision seeder from the producer Lemken, all operating functions of all trailed slurry tankers from the company Zunhammer and the potato harvester from the manufacturer Grimme were analyzed. In order to obtain an extensive coverage of the operating functions, a fully equipped version with the widest possible range of functions was selected for each of the listed implements. During the interview, the experts showed the display of the UT. The UT was previously provided with the necessary data to systematically collect and discuss all individual functions of the individual implements during the survey. Given the scope of the survey, only specific details of the content and results of the expert interviews will be presented here. To give an impression of the structure and content of the questionnaire for the expert survey, an example is shown in Table 1. The individual functions are recorded one by one in the horizontal direction and then evaluated by the expert in the vertical direction on the basis of various evaluation criteria. The evaluation criteria are intended to provide a basic assessment of the expert for the respective operating function. The first criteria has a special position because the function itself is recorded and reduced to its underlying operating characteristics, such as right/left, up/down, forward/back, rotate/swivel, on/off and increase/reduce (Kaufmann et al. 2020), and finally summarized in operating scenarios (OSC). For a better understanding, it is possible to look at the so-called "pick up" function using the loader wagon as an example. It is a swath roller that uses several rows of tines to pick up material from the ground and transport it into the loading area. In the first step, the functions are reduced to their underlying operating characteristics and defined as "lowering pick-up" (working position) and "lifting pick-up" (leaving the working position). The two individual functions are now combined into one OSC with the description "pick up" and the two states "up" and "down", which is described in the first line of the table. Different evaluations of the different operating directions, which result, for example, from short actuation to lower the pick-up and long actuation to raise the pick-up, are also taken into account in the recording. The individual OSCs are combined into function groups (FG), which together form the higher-level operating scenario "loader

Table 1. Excerptof the expert interview for function recording and evaluation.

Evaluation criteria / Operating functions		Function group (FG)	FG 1		FG 2			FG ...
		Operating scenario (OSC) / Characteristic	OSC 1	OSC 2	OSC 3	OSC 4	OSC 5	OSC...
Criteria	Explanation / Scale							
States	Functions are described by their functional characteristics and grouped into OSCs	States of the OSC						
Current operating technology	Currently used Operating technology	Touch operation						
		Real operation						
Blind operation	Control element has to be reliably operable without having to look at it	Yes						
		No						
Operating frequency	Assessment of the operating frequencies	Evaluation scale 0 - 4						
Moment of operation	pre / intra / post: Operating function is executed before / during / after the work task	pre						
		intra						
		post						
...	...	...						

wagon" in the overall operating system of the agricultural tractor. A total of twelve criteria were evaluated for each function. In addition to the evaluation criteria shown in Table 1, the following aspects were evaluated: Assessment of the optimal operating technology (virtual or real), operating time, safety-criticality of the function, simultaneous operation with other functions, user customizations and updateability of the functions by the manufacturer.

The expert survey resulted in a total of approximately 230 OSCs with an average of around 19 operating scenarios per implement. Since each OSC consists of an average of two individual functions, the expert survey covered around 460 functions, which were each evaluated according to the twelve criteria mentioned above. The information from the evaluated functions is then incorporated into the following method in form of the evaluated OSCs.

Function and Operation Analysis

To understand the following method of the function and operation analysis (FOA) it is important to take a look at the different compatibilities that should be considered when designing an intuitive HMI. There are different compatibilities, which describe the motion correlations and the respective meaning between the control element, the indicator and the active part. The time compatibility arises from the temporal assignment between operation and function execution. The meaning compatibility describes the meaning of the directions of movement whereas the motion compatibility describes the correspondence of the directions of movement of the active part and the control element. The spatial compatibility describes the spatial arrangement of the control elements according to the position of the active parts. In addition to the compatibilities, the principle of consistency applies within an interface system. This means that basic definitions and designs are retained throughout the entire interface system in order to avoid contradictions within the operating logic. For example, if the direction of rotation is positive to the right, all similar control elements or control functions should also have a positive direction of rotation to the right (Schmid, 2017).

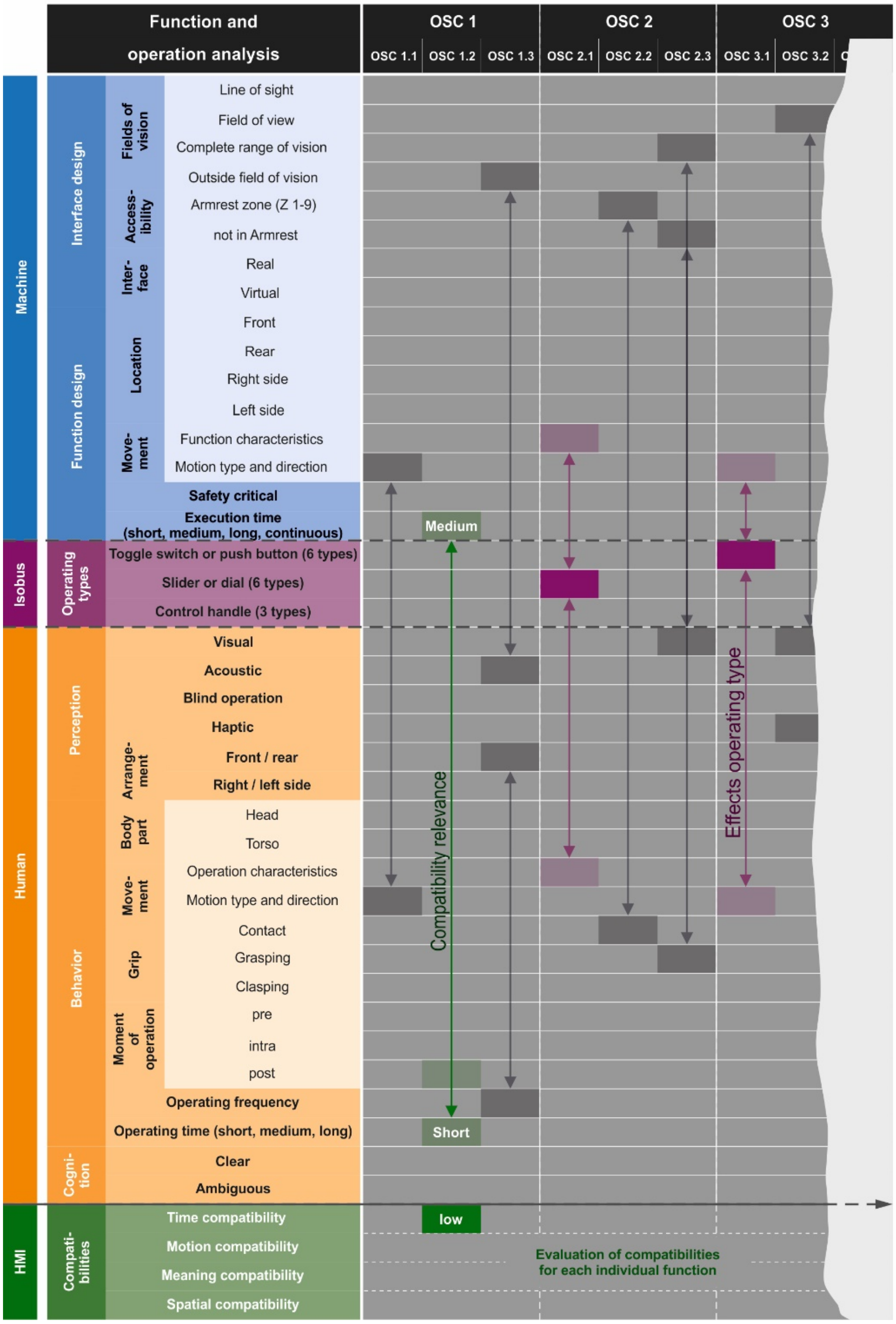
In order to understand the extension of the FOA, it is also necessary to take a look at the Isobus communication standard used in agricultural tractors. The implements considered are exclusively Isobus compatible machines. This is a prerequisite for the intended adaptive control system, because only through this communication interface an automatic and standardized recognition of the changing implements is possible. The Isobus communication standard is defined in detail by the ISO 1178 (ISO 11783, 2018) and is used for the communication between tractor and implement. The interface system to be developed should use this information and adaptively adjust to the new implement as soon as it is coupled. The centerpiece of the current HMI by the Isobus standard is the previously mentioned UT. In general, all settings and operating functions of an implement can be mapped on the touch display of the UT. Functions that have to be operated by real control elements are defined via the so-called AUX (auxiliary control) interface. In this context, real operating elements refer to all operating functions that provide haptic feedback from the control element, unlike the virtual operation via touch displays. The AUX functions in the ISO 11783-6 are based on fifteen different types, which define the type of how a control element can be operated. These AUX categories only define the type of operation and are not related to position, operating direction or the actual hardware solution of the control elements. This means that the AUX types describe the software input that is defined for a specific function. For the implementation of real operating elements, further degrees of freedom in the design and positioning can be used. For example quantity changes can be implemented as sliders or dials, or a non-latching push-button can be installed in a vertical or horizontal orientation.

Applying to the function and operation analysis, the results of the expert interviews are used as input information and the individual operating scenarios are analyzed with regard to various criteria. Design recommendations can be derived based on the described compatibilities. The original FOA is presented in detail by Kaufmann in his article (Kaufmann et al., 2020). Its objective is the detailed analysis of the correlation between the operation on the human side of the interface and the respective machine-side component that executes the operation. The analysis of the machine (Table 2, blue area) includes interface and function while the analysis of the operation by the human (Table 2, orange area), includes perception, behavior and cognition. Table 2 shows the further developed method. In addition to several parameters from the expert interviews, the FOA was expanded to include another two important aspects.

First, a systematic examination of the compatibilities was added (Table 2, green area). Each function is evaluated on the basis of the relevant parameters for the compatibility between operation and execution of a function. For example, in addition to the parameter‘s execution time and operating time, the moment of operation or the type of operation can also be important for the evaluation of time compatibility. In summary, the information provided by the compatibilities leads to specific requirements from which clear design recommendations can be derived.

For the other modification of the FOA, the above mentioned AUX types were implemented in form of operating types (Table 2, purple area). Thereby, a general differentiation is made into three different areas, resulting from the type of operation: Toggle switch or push button, slider or dial and control handle. The three areas are subdivided themselves into several types. For example, an analog slider can have different versions such as “Slider”, “Slider - returns to middle position”, “Slider - returns to zero position” or “Slider - returns to zero position, end positions latching”. One or more of the mentioned AUX types is assigned to each operating scenario and the operating type is specified in detail in the corresponding field. The most important criteria from the FOA analysis that influence the design of the Isobus operating types are the function characteristics and motion type and direction on the machine side and the operation characteristics and motion type and direction on the human side. Taking the compatibilities into account, an important first design recommendation can already be derived from these parameters.

Table 2. Extended Function and operation analysis based on (Kaufmann et al. 2020).



Depending on the considered OSC, different parameters may have different influence on the Isobus types as well as the design recommendations based on the compatibilities. The fact, that each function must be examined in detail for all interrelationships results in a complex evaluation. However, as a result, a very detailed information basis is created at the end of the process. Due to the extensive methodology and the equally extensive results of the various implements, only examples of the results can be presented. In order to better understand the relationships between the operating types, the function group (FG) “Suction trunk settings” from the implement “trailed slurry tanker” from Zunhammer can be viewed. This function group contains various OSCs relating to the “Suction trunk”. The OSC “Suction start/stop”, for example, is described on the machine side by an on/off characteristic which can be described in a meaning-compatible way by a latching toggle switch (similar to a light switch) or a simple push button. The two OSCs “suction arm height adjustment” and “suction arm swiveling” differ in their functional characteristics on the machine side by a vertical up/down movement and a horizontal right/left movement. They have a high time compatibility and are used with a high operation frequency. This indicates an ergonomically optimal placement in the visual range of the user’s field of view at a location that is easily accessible. The common use in terms of time as well as the request (expert interview) for simultaneous use of the two OSCs in the future also indicate a combination of the control elements. In summary, this indicates an assignment to a joystick, which has the vertical axis and can represent the horizontal movement by a forward/backward tilting movement with meaning compatibility. Taking the analysis into account, this leads to the following solutions for the Isobus operating types: “non-latching digital cross-function control handle” or “cross-function control handle with return to center position”.

DISCUSSION

In summary, the requirements for the adaptive operating armrest are achieved by the detailed analysis of the operating scenarios, the operating characteristics, the investigation of the compatibilities, and the consideration of the operating types. The results of the presented methodology lead to specific design recommendations for a conceptual design of the adaptive HMI for the control functions of the different investigated implements. The FOA was extended by the AUX types with a new component for the design recommendation and thereby further optimised for the specific application. To take the functions of the tractor into account as well, the methodology described above will also be applied to the tractor and its requirements will be implemented in the design recommendations. In order to apply the results of the study in a more general way later on, the next step is to abstract the results in order to make them transferable to such implements that were not investigated. In a further step, a precise mapping of the operating functions to the operating armrest is carried out, which leads to a further improvement of the design requirements.

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