The Art to Make an Error: The Dilemma Between Prevention, Learning and Mitigation

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Abstract
Background Following the established tradition of user centered system design leads to the effect that erroneous behavior of human operator and technical system shall be minimized. As this development goal is in most system constellations to advanced the question on avoidable consequences is more suitable. On the other hand erroneus behavior is a source of information and learning for human operators.
Methods Experiments with user adaptive systems show that adaptiveness includes the risk that system transparency is reduced and the user is not able to handle erroneous situations.
Results The examples show that more information presentation instead of adaptive systems could solve the dilemma and provide learnable environments that keep the user proactive. Additionally it can be shown that there is only limited understanding by the user for technically driven errors in adaptive modules which makes learning difficult at all.
Conclusions Interaction design should take into account that an enabled user is an important part of an error robust system. To ensure these capabilities transparent information presentation is a clear alternative to opaque user adaptive systems. Moreover this approach could help to keep software complexity in a manageable level.

Keywords Error · Adaptivity · Human Machine Interaction · Automation

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Introduction

In a long tradition of user centered system design numerous developers followed the goal to minimize the risk resulting from erroneous behavior of human-machine-systems. Another simultaneous goal is to maximize the efficiency of the whole human machine system (HMS). Whereby—generally spoken—risk minimization can be achieved by minimization of error frequency or error consequences, there is an ongoing tendency to maximize efficiency by automation which results in an increase of monitoring tasks for the human operator. Examples are the layout of pilots' workplaces, vessel operation and increasingly car driving (Fig. 1).

Efficiency by User Adaptive Systems

Therefore it is of increasing importance given a high level of automation to achieve the notorious error free system. The resulting problems evolve from the lack of 100% reliable technical systems and the challenge to draw the line between human erroneous behavior and natural variability in human behavior. Especially in case of efficiency optimization there is a big motivation to reduce human variability. This can be achieved by a priori training, exercise and experience; or by task reduction and increasing process automation which leads in many situations among others to effects of skill reduction and system opaqueness. It should not be overseen that both components (human and machine) get less error robust by this strategy as the interaction is now less sensing and touching and the technical system is more complex and possibly error-prone. The system design is running into a complexity paradox: more safety shall be achieved by more system complexity which causes more weaknesses and less transparency of the machine part of the system for the user. In many cases training efforts are cut and focused to the remaining tasks, weakening the users' general capabilities.

As those effects and discussions are already well known and frequently treated problems it is justified to ask why to discuss them once more.

From the author's perspective the well known effect is amplified by a tremendous emphasize of efficiency and performance requirements. Second, in many

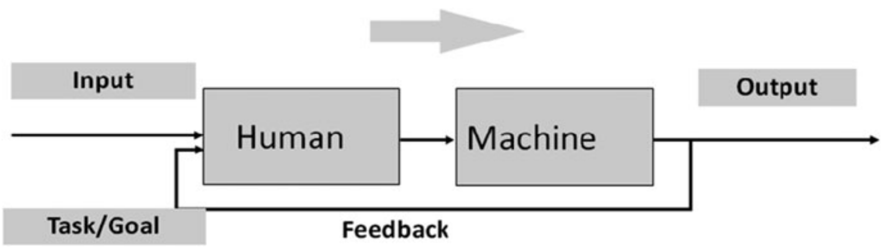

Fig. 1 General model of the human machine system

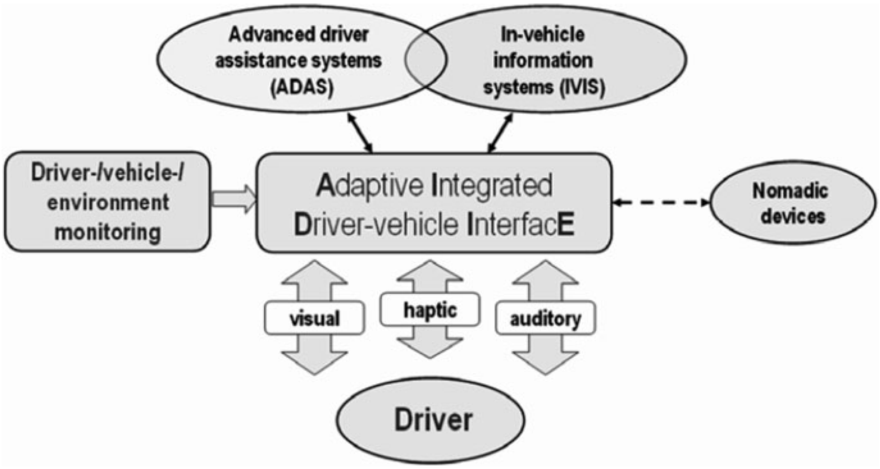

Fig. 2 Illustration of the AIDE concept as an example for a user-adaptive system architecture [1]

cases user modelling and adaptive systems promise to resolve this situation as a panacea (Fig. 2).

Technically spoken the machine is extended by sensation, recognition and interpretation modules that try to build and maintain a user model due to the behavior of the user. This approach is enabled by developments in sensorics, storage und processing. The status of those can be experienced for example in the current DARPA demonstrators which replace the user at all. In everyday life we can experience those systems in dialog system behavior of browsers.

Due to these two facts it seems reasonable to ask whether human operators have learning strategies to interact with imperfect “should-be-intelligent” user adaptive machines implementing a user model and are able to take their decision and error characteristics into account under efficiency pressures. This discussion follows Reason’s argumentation of systems that implement “unfamiliar or unintended feedback loops” [2].

Examples that can be named in this case are again natural spoken dialog systems but also semi-autonomous transport systems. In the case of spoken dialog typical technology driven recognition errors do not meet user expectations based on human–human interaction and lead therefore to curious and non-efficient problem solving behavior by the user e.g. repetition of commands, inefficient trial and error

Currently in many warning systems only a very restricted and simple reaction time based user model tries to resolve the warning dilemma. Given a stable reaction time of the user the system will not warn before and warn or act after a given time-to-collision. Unnecessary warnings and misses shall be avoided using this approach. To some extent this leads to a stable and reliable solution of a technical system.

Adaptive Systems vs. Learning Users

Analysing advanced architectures for future systems unveils in most cases a classical system design including extended user models that assess user state, intention and availability to moderate the system behavior. It is important that these models are based on sensoric input and probabilistic recognition processes of context information which means that their status and influence on system state changes are more or less unlearnable for the user.

Therefore it is of interest whether the existance of an adaptive machine will lead to a change in error qualities and error type distributions (Omission vs. Commission; Active vs. Passive). One result could be that the user is disabled to act as a safety barrier once more. Moreover human variability would again be counterproductive for a stable user model.

This leads to the question whether there is an alternative approach which incorporates human variability into system design and enables the user to build up experience while interacting with the system. The art to make an error cannot mean to increase technical system deficits and make the system more error prone but to make the whole HMS more error robust based context information for an active learning intelligent user. As pointed out in Hollnagel [3] "Errors are useful for learning". On the other hand Reason [2] warns that in all day behavior errors are an important source for learning. In complex systems this has to be avoided: "Whereas in the more forgiving circumstances of everyday life, learning from one's mistakes is usually a beneficial process, in the control room of chemical or nuclear power plants, such educative experiences can have unacceptable consequences." Therefore it has to be investigated whether requirements for learner friendly controllable environments and architectures under efficiency conditions have to be defined for critical environments, too:

- increase of system transparency and feedback to the user
- increase of user involvement and continuos user activity
- decrease of the degree of precise technically automation
- limitation of probabilistic active technical functionality

This seems justified as another group of enabling technologies would also be available in form of advanced display technologies, force feedback actuators, and forward propagation based on ambient information and connectivity to the environment. The goal in this case is to focus on interaction designs based on prospective information presentation instead of monitoring of automated functionality.

It has to be taken into account that the challenge in this case is the limitation of information overflow und successful information integration for the user. Again the target is to establish a learner friendly environment in which the user is able to acquire the necessary skills and routines to optimize overall system efficiency under standard conditions in an anticipative way and limit the consequences of technical errors.

Information Design for Anticipative Driving Behavior

One example is the realization of an anticipation horizon for the car driver using C2X information to provide the driver with information on the further development of the driving situation. The information displayed in the dashboard integrates speed limits, curvatures as well as traffic jams and accidents. It can be shown—although the information is provided in qualitative way—that drivers are motivated to integrate this information into their driving strategy and establish a very anticipative driving style which is fuel efficient and safe as well. In driving simulator experiments the dedicated layout of information presentation especially the incident category which is provided by CarToX connectivity leads to high acceptance and specific behavior. Due to the fact that the CarToX information is incomplete and to some degree unreliable, one has to speak of erroneous technical information in this case. It could be shown in experiments that users are able to use this source of information and transform it into stable error free and efficient driving behavior [4] and without adaptivity on side of the machine.

Summary

This shows that the try to model human error into adaptive system design may not be enough, but moreover counterproductive. It might be reasonable to increase system's stability, transparency and enable the learning user as an anticipative source of safety and efficiency by better visualization. Noted problems to realize this concept like information overflow and increased workload could be solved by innovative technologies that enable integrated presentation of complex data and forward propagation of process states by enhanced system simulations.

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