Effects of automation to the surgeons

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Abstract— In this paper, part of the invited session - Automation in medicine, the different effects of automation to the surgeon are discussed, including positive and negative consequences. One approach to analyze effects of automation is explained, and exemplarily shown on a study of the mode error at the computer assisted surgery (CAS) system navigated control.

Keywords— Automation Consequences, Navigated Control, Mode Error, Evaluation.

I. INTRODUCTION

Automation can be defined as a device or system that accomplishes (partially or in full) a function that was previously, or conceivably could be, carried out (partially or in full) by a human operator [1]. Automation is any sensing, detection, information-processing, decision-making, or control action that could be performed by humans but is actually performed by machine [2]. In a modern operating room (OR) are many examples of automation to observe. It is important to investigate the effects of automation to the human-machine interaction (HMI). In this context the results of a study by Matern et al. [3] of German surgeons are interesting: 70% of the surgeons declared that they can’t fully control their systems and 52% of the surgeons were wishing an improvement of the usability of technical medical systems. These results show the importance of the analysis of the HMI in medicine. Based on this situation basic concepts of automation and framework requirements in the context of medicine are explained. The approach is explained on the example of the computer assisted surgery (CAS) system navigated control.

II. AUTOMATION IN SURGERY

Positive and Negative Automation Consequences: The goal of automation is to increase flexibility, efficiency, accuracy and safety. These goals can only be reached if automation is running free of errors. If the automation is erroneous the human has again to take control of the process. Because of relying on the automation, he might not be prepared for controlling the machine manually. Hence the human may react inadequately in such situations (“Ironies of automation”, cf. [4]).

To avoid such situations, it is important to use “human-centered automation concepts” for the design of human-machine-systems. A central assumption for “human-centered automation” is the following, cf. [5]:

The user has to have the ability to recognize his responsibility and functions during the complete process of applying a man-machine-system. In surgery this means, the surgeon always bears overall responsibility for patient safety. Surgeons always must be in command of the surgical process.

Human Performance Consequences Various authors have defined evaluative criteria for such a human-centered automation design. These criteria are called “human performance consequences” (Tab 1).

Table 1 Criteria for Human Performance Consequences

<table>
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<th>Criteria</th>
<th>Description</th>
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<tr>
<td>Trust into automation</td>
<td>The belief of a person, that the machine will support him in an uncertain situation (cf. [6]).</td>
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<td>Commission Error</td>
<td>Obey an automatically generated wrong advice without verification and although further contradictory statements are available [7].</td>
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<td>Omission Error</td>
<td>A lacking response on a system error, because the automation does not show this system error either [7].</td>
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<td>Complacency</td>
<td>The lack of human control of a (automation) device; i.e. the operator is performing control more seldom than the automation of the system would require [1; 8].</td>
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<td>Loss of (manual) skills</td>
<td>With the introduction of new systems, the users may loose the ability to finish a task in the traditional way in case of a system’s failure. Further with automation systems some manual skills may not be taught to the novice surgeons [1].</td>
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<td>Maintaining situation awareness</td>
<td>Situation awareness is the subjective representation of the work environment, i.e. the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status into the near future [1; 9].</td>
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<td>Cognitive Workload</td>
<td>Evidence shows that automation can lead to decreasing or increasing mental workload [10].</td>
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<td>Mode error</td>
<td>When a user misclassifies the mode resulting in actions that are appropriate for the analysis of the mode but inappropriate for the true mode [11].</td>
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All these criteria may also influence the surgeon’s performance if he/she is using surgical automation systems. For the evaluation of these effects of automation, a framework is used, which was developed by Jannin and Korb [12], based on the standards of the Health Care Technology Assessment (HCTA).

In this paper that framework is applied for the assessment of the effects of automation. The first step in the framework is a careful study planning with the following tasks:

1. **Systems description**: Definition of the system and the system status in the engineering life cycle (design, sample, prototype, certified system, etc.)
2. **Surgical context and intended use**: This includes a description of the surgical procedure followed by the surgeon when using the system.
3. **Assessment level**: HCTA defines different assessment levels, to categorize the intended assessment objective:
   - Technical feasibility,
   - Reliability of the system,
   - Efficacy, i.e., the benefit of using a technology for a particular problem under ideal conditions,
   - Effectiveness, i.e., the benefit of using a technology under general conditions,
   - Efficiency,
   - Social, legal and ethical impacts.
4. **Criterion and measures**: For the described system in a specific surgical context, a study objective needs to be defined. This means to select one of the criteria of Tab. 1 and an appropriate measure (please refer to the indicated references in Tab. 1 for each criterion). This decision allows also defining the hypothesis.
5. **Study conditions**: After the study objective and the hypothesis are defined, the conditions that can further influence a study are considered: scenarios, operators, locations, environment and patient data sets.
6. **Assessment methods**: A detailed description of the methods, including metrics, statistical analysis and calculations of the results need to be done, before conducting the study.

After study planning, the framework recommends conditions how to perform the study and how to report the study [12].

To demonstrate the approach of the framework, in the following section the method of study planning is applied for an investigation of the navigated control system (NC).

### III. MODE ERROR IN NAVIGATED CONTROL (NC)

**Systems description and intended use**: NC [13] is a surgical navigation system which has two different modes. Different modes are a common architecture in modern machines [14] they represent different states or functions in a certain system [15]. In the “free mode” the surgeon can use the navigation and has no limitations for using his surgical tool in the *situs*. In the “navigated controlled” mode the system automatically switches off the surgical instrument in pre-defined areas of risk. These areas of risk are defined preoperatively by segmentation of the “region of interest”. If the tip of the tracked instrument is within this region, the instrument performs the milling, outside this region the instrument is switched off, even if activated by the surgeon with the foot pedal.

These NC-systems are currently in the development status “performing clinical patient trials” [16; 17].

**Surgical Context and intended use**: Currently these systems are available for endoscopic rhino surgery, otosurgery (mastoidectomy), dental implant drilling and spine surgery. For the use of NC some preparations are needed. First a workspace planning is necessary, which includes a fixation of markers to the patient for the later registration. This is followed by a CT-scan of the patient including the markers. The preoperative segmentation, so that the areas of risk will be save, is done in this CT-scan. The workspace model is imported in NC, than the scanned markers on the patient and the instrument are registered to track the patient and the instrument intraoperatively. Finally NC is used for milling and to remove tissue e.g. bone.

**Assessment Level**: The authors were interested in the effects of automation and the consequences to the reliability of the system (Level 2)

**Criterion and measures**: It may be dangerous if the user doesn’t know in which mode he is in [15], because an identical user input is interpreted differently by the system in different modes [11]. If the user anticipates that he is in a certain mode and acts correct for the anticipated mode but incorrect for the real actual mode it is called a *mode error* [11].

Through a frequent mode change or an unplanned event (i.e. other medical complications or other deflections) it can come to a limitation of the knowledge about the current mode. So that the surgeon doesn’t know in which mode he is in. Reasons for a mode switch can be for example the personal preferences of the surgeon or a changed situation...