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Hands-Free Mechatronic Movements

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Abstract: This paper explores hands-free mechatronic movement in medical imaging devices, emphasizing the transition from dead-man grip (DMG) control to autonomous operation. Central to this development is a robust safety architecture with redundant and diverse sensors, which enables the implementation of advanced features. This provides a level of safety comparable to manual scanning, so that psychological requirements for user trust are also met. Crucially, the system design supports a fallback to DMG-operation, ensuring both flexibility and user acceptance as autonomy increases.

I. Introduction

Future staff shortages may negatively affect the quality of medical care [1]. The physical stress and non-ergonomic design of equipment further diminish the attractiveness of healthcare professions. Implementing medical imaging devices – such as such as X-ray systems, CT scanners, MRT scanners and PET scanners - with a degree of autonomy in mechatronic movements could offer a solution [2].

This paper explores hardware and patient handling autonomy [3], with a specific emphasis on mechatronic movements.

The degree of user interaction varies according to the level of autonomy (see Figure 1). For this paper partial autonomy at level 3 and autonomy at level 4 are most important.

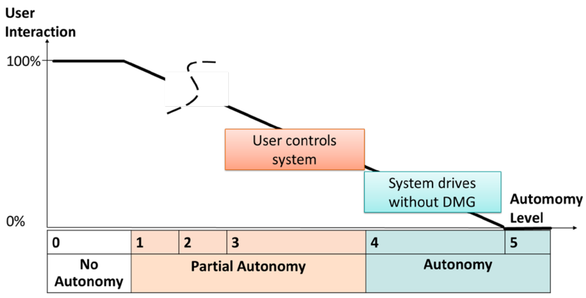

Figure 1: Levels of autonomy

At level 3, mechatronic movements of medical systems like X-ray machines, must be supervised by the personnel who press a dead-man grip (DMG) for control [4].

To enable autonomous functions without personnel supervision at level 4, a single-fault safe architecture is essential [4]. This is also the regulatory basis for the later implementation of more sophisticated autonomous features [5]. It is important to note that starting with level 4 the responsibility of the movements changes from the user to the manufacturer of the imaging device [6], [7].

II. Hands-Free Movement

Radiologic technologists prefer to control medical devices - hands-free - and concentrate more on the patient. According to the risk assessment this leads to a specific safety architecture.

The selection and combination of sensor technologies are crucial for ensuring safe autonomous movements in medical devices. By implementing redundancy, using multiple sensors of the same type and diversity[3], combining different sensor types such as ultrasonic, radar, and camera systems, the overall reliability and fault tolerance of the system are significantly enhanced [8].

Single fault safety is realized through self-tests and redundancy, which are essential in defining system architectures [9]. Self-tests occur at start-up to detect errors within the multiple fault occurrence time (MFOT) and at runtime to identify faults within the failure tolerance time (FTT).

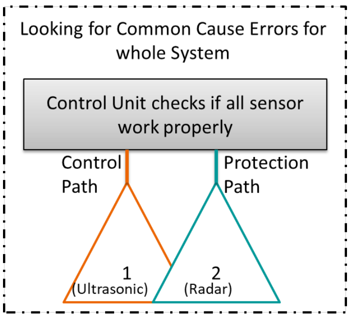

Figure 2: CP architecture

A typical structure is the CP-System in one hardware unit (see Figure 2) [10]: It combines control (C-) and protection (P-)Paths within one controller. The necessity of self-tests depends on the diversity of these paths to prevent common cause failures. Independent supervision and shutdown paths are tested within the MFOT.

Furthermore, the concept is to rely on simple and cost-effective sensor technologies, such as ultrasonic or radar sensors. At first glance, this may not appear to be a significant challenge. However, when considering current market availability and the high-cost sensitivity of healthcare systems worldwide, this represents a crucial and non-trivial step. Additionally, the presented architecture not only enables advanced hands-free functions but also ensures that reverting to Level 3 operation with a dead-man grip remains possible at any time.

III. Driver for new features

An underlying safety architecture additionally allows the usage of more sophisticated algorithms for path planning and collision avoidance (see Figure 3). While the safety path is the final bastion for collisions, the comfort path includes features which during normal operation should be so good that the safety shield is never breached. This separation is important as parts of the software used in the safety path will be classified as Class C, and sensors are either redundant or single-fault-safe. These efforts are not needed in the comfort path. Furthermore, the system could use the same sensor information in both path, but they are generally independent of each other.

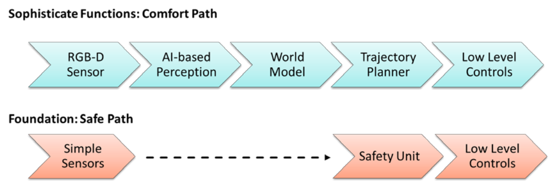

Figure 3: Safety and Comfort Path

The introduction of new features is only feasible because the underlying safety concept guarantees both operational safety and regulatory compliance.

IV. Combination of Level 3 and 4

Apart from technological and regulatory challenges, psychological aspects must not be forgotten [11], [12]. Although there is a staff shortage not every user might approve of a higher autonomy level of the medical device, reducing their own possibility to control the system.

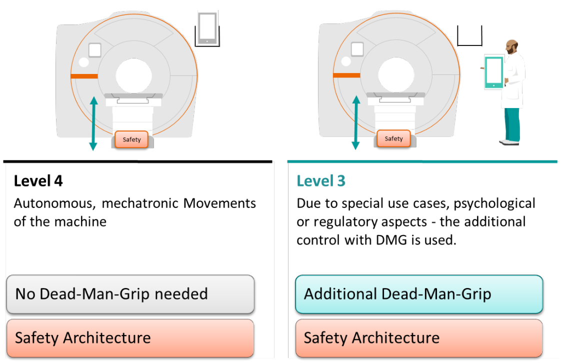

Figure 4: Combination of Level 3 and 4

In this case, the feature of leaving out a DMG at autonomy level 4 is downward compatible to level 3 (see Figure 4) – at least from the user's point of view. It is possible to provide an additional DMG which overrides the safety path. The option to switch back to supervised operation increases user trust and acceptance of autonomous features.

This solution might be also needed for special use cases where the safety architecture is not yet sufficient. For example, the examination of babies and small children. Focusing on collision avoidance, they are more vulnerable than adults. Furthermore, their limited cooperation during the examination introduces an additional risk to the workflow which must be mitigated.

Of course, this increases total costs slightly, but at the same time provides a solution for a broad field of users. According to Mayer's trust model, user trust and machine behavior form a feedback loop. When the system behaves as expected, trust increases, and staff may omit the DMG after a certain period. [11], [12], [13].

V. Conclusions

Hands-free autonomous movements in medical devices require reliable safety architectures and attention to user trust. Such architectures not only enable advanced autonomous functions but also ensure a seamless fallback to supervised Level 3 operation when needed. This dual strategy drives innovation while maintaining the highest standards of safety and user acceptance.

Author's Statement

The author state no funding involved. Authors state no conflict of interest. No informed consent required.

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