# Design of a Guided Missile Operator Assistant System for High-Tempo Intervention Support

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**Abstract.** Controlling a short-range missile with in-flight reconfiguration capabilities places high demands on the design of the missile operators' control station and automated functions. To enable the missile operator to react fast, reliable and in a responsible manner to unforeseen events, e.g. high risk for collateral damage, an automated decision support system is investigated in this article. A common approach to reduce the high time demands of the operator is to transfer more functions from the human to the machine. Such emerging high levels of automation introduce ethical problems as well as new issues in human-automation-interaction to be resolved. At the Institute of Flight Systems we follow a well-established approach of human-automation cogency to assist human operators while keeping them fully involved in decision processes, i.e. "dual-mode cognitive automation, DMCA". This article presents first steps towards the application to a high-tempo mission with minimal information on the task and the tactical environment being available to the automated system.

We present an approach to relieve the human from the time critical task to enter suchlike information into the system, thereby freeing cognitive resources for mission critical decisions. At the same time the assistant system observes the actions of the missile operator, infers his/her most likely intents, and adapts support functions accordingly. Comparing the human's control actions with intention related task models, the assistant system shall identify errors and suggest alternative actions or possible solutions. The operator remains in full control of all functions and decides whether to accept or decline the assistant systems advises. This article provides an overview over the main conceptual ideas and the current status of prototype implementation.

**Keywords:** missile operator, intervention support, levels of automation, assistant system, intent recognition, adaptive automation.

## 1 Introduction

At the Institute of Flight Systems (IFS) at the University of the Bundeswehr Munich (UBM), the characteristics of a short range guided missile mission are subject of research. State of the art so-called fire-and-forget missiles are capable to engage the designated target with a high degree of reliability. Before launch, the missile is

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programmed with cruise waypoints and the target signature. The onboard navigation and seeker head enable the missile to automatically find its way to the target without the need or possibility for human intervention after launch. However, in case of an unforeseen event occurring at the target area, for example the detection of uninvolved civilians, the fire-and-forget strategy can cause massive and totally unacceptable collateral damage. This is why today the requirement arises to enable a human operator to intervene even at very late stages of the missile flight [1].

In this article, the characteristics of controlling a missile with reconfiguration capabilities in flight are examined. Therefore, we look at a missile which is controlled by a human missile operator from a ground control station outside the battlefield. Targeting information will be provided by an infantry soldier in the field, the so-called spotter. Upon fire request the tasks of the missile operator are to plan the flight trajectory for the missile and to configure the seeker. After launch, the missile will be monitored and controlled via data link. This technically allows the operator to react to unforeseen events in the target area.

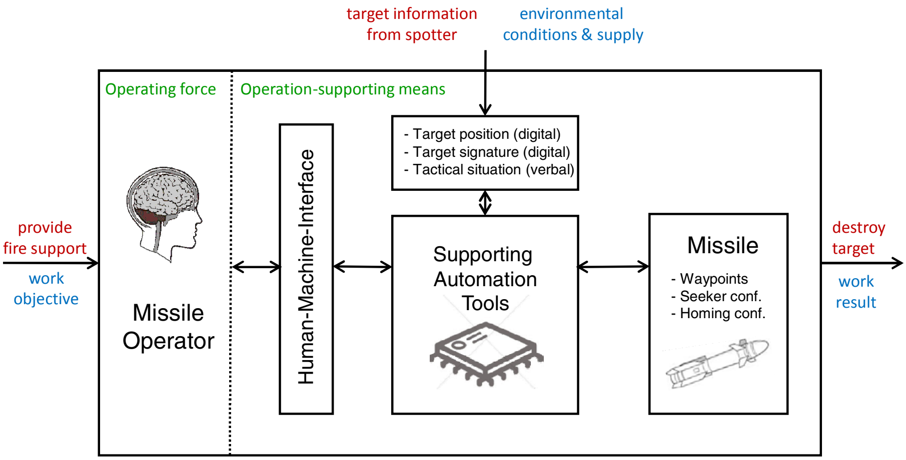


**Fig. 1.** Work System of Missile Operator

To better understand the connectivity between missile operator, spotter and missile, the corresponding work system is shown in Fig. 1. A work system represents the components which accommodate the functions of the underlying work process [2]. The operator constitutes the operating force. His/her work objective is to provide fire support by planning the missile mission, executing and adapting it to possible changing demands. He/she can interact with the missile through an HMI and the help of supporting automation tools. Information about the target is received from the spotter in the field. This information consists of digital data which can be processed directly by the supporting automation tools like the target position coordinates and the target signature. Information about the tactical situation is only transmitted verbally to the missile operator, though.

The flight duration of the considered short-range missile is usually not much longer than one minute. In case of an intervention request, the missile operator has only very limited time to adapt mission parameters. Besides commanding a mission abortion, the operator has the option to adapt the flight trajectory, change to an alternative target, or modify the target approach configuration (azimuth and elevation angles). This high-tempo, high-workload environment reaches the limits of human sensory and cognitive abilities, driving the need for automated support systems [3].

The following chapter will dwell upon the fundamental problems in defining the right aggregation level of interaction to be chosen for the human-machine-interface design. This question is frequently oddly associated with the term level of automation (e.g. [4]).

## 2 Analysis of Interaction Level

In cognitive ergonomics the design of automation functions and human-machine-interface should follow the well-adjusted allocation of functions between the human and the automation. Especially in the application we are looking at, which is heavily driven by high-tempo lethal decisions, ethical as well as cognitive performance aspects are the driving factors.

Not only from an ethical stance it is recommended to always keep the human in the decision loop. The missile operator is responsible for a successful yet justifiable mission outcome. Therefore, he/she should be aware of the situation and capable of acting at any given point in time. Only with complete knowledge about the situation, the operator can project decisions in time and decide when and how to intervene. Regarding the fact that there is only very little time remaining for this, once a missile has been launched, high levels of automation, in its extremes "full autonomy" might look like a tempting choice, although corrupting aforementioned principles. Lower levels of automation, i.e. in our case levels of abstraction in the interaction concept with automated functions may result in the necessity of a vast number of control actions of the human with the system. In its extreme the operator would be demanded to enter each single trajectory point and parameter into the system manually. The advantage of such low level of automation is that it provides full control over and direct access to all functions and sub-functions. On the other hand, given the high-tempo environment excess high mental and even physical workload would be the consequence.

Higher levels of automation and abstraction can reduce and simplify interaction with the downside of possible opacity of the background processes of the automation. The operator may easily get out of the decision loop by not fully understanding the automated processes. Not in all cases it can be assured that a highly aggregated macro-function offered by the automation (e.g. "abort mission") will result in what the user actually intended or expected.

In case of an intervention request caused by an unforeseen event, the task of the missile operator is to adapt the mission accordingly. Therefore, the system has to provide appropriate functions covering all possible occurring use cases. Taking into

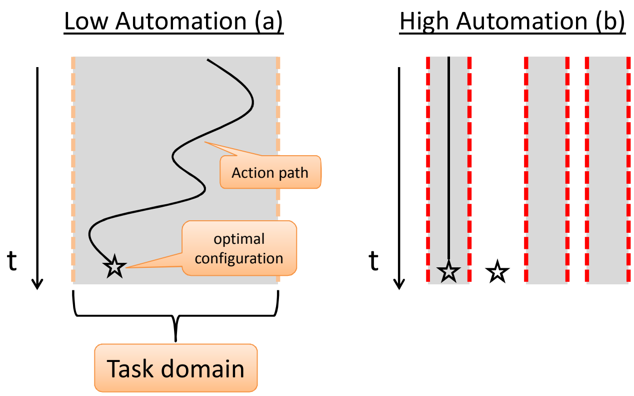


**Fig. 2.** Comparison of different levels of automation abstractions

consideration the previous discussion, the question arises which level of abstraction is the right one to choose? Fig. 2 illustrates a possible course of action for the missile re-tasking given different levels automation abstraction.

As depicted in Fig. 2 (a), with a low automated system, the operator can choose from a wide range of actions alternatives to achieve the desired outcome. In this setup, the operator should always be able to define an appropriate action sequence. But taking into account the high-tempo environment, too much freedom of choices can prevent finding the shortest command sequence and produce unnecessary delays, or the number of required interactions to do the job is just too high to be accomplished within the given time frame.

On the other hand, with a highly automated system Fig. 2 (b), the missile operator may trigger one of very few predefined action sequences, which have been configured during design time of the system to achieve a certain outcome. Most likely it would be the case that the very situation would demand for slightly deviating adjustments, which are not possible to be entered into the system. In this case the operators' work demands may be massively below the ones described before with the downside of cutting back his/her authority. Once initiated, the action sequence will be executed automatically, prohibiting the operator of further interventions. In case the situation demand for a solution not considered at design time, the automation fails to offer appropriate functions. Additionally, a high level of automation switches the operator's activities to monitoring automated carried out tasks. Too much confidence in the automation can lead to complacency, skill degradation and loss of situation awareness [3]. The operator cannot fulfil his responsibility for the mission by just accepting and not fully understanding the impact of the automated task processing.

A first approach to reduce the disadvantages of the configurations described above is to choose a moderate level of automation abstraction - high enough to limit the required number of interactions, low enough to permit deviation and to retain authority of the system. In the considered missile mission with changing demands over time, the optimal level of automation strongly depends on the current work objective of the operator. In this environment a static design of automation does not look suitable to provide optimal support.

In [5], an alternative approach is proposed by adapting the function allocation between human and machine to the current needs. Therefore, "Adaptive Automation" needs to know the work objective before being able to adjust the supplied supporting tools. In our application this could be realized by implementing a dialog system to enter the missing information. The resulting additional interaction step for the operator would lead to an increased workload, though, which is not desirable during an already stressful situation. Additionally, by integrating adapting function allocation, the operator is confronted with suddenly changing operation procedures.

In this article, an alternative approach is proposed. A low level of automation abstraction is chosen to allow the operator to retain full control. In addition to this conventional automation, an assistant system is introduced to adaptively support the operator during high demanding situations. The current work objective of the operator is recognized by observing the actions of the operator, using an intent recognition algorithm. Thus, the described additional dialog system can be avoided. The probability of inferring the correct work objective is increasing with each interaction step executed by the operator. After reaching a minimum threshold probability, the assistant system can support the operator achieving his/her objective by comparing and evaluating the upcoming action path to an appropriate underlying human action model.

The design of a missile operator assistant system is described in the following chapter.

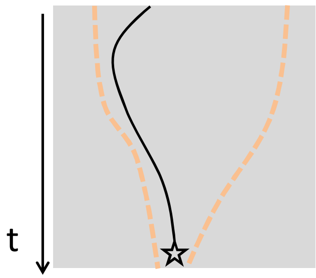


**Fig. 3.** Assistant System – principle of operation

Fig. 3 summarizes the principle of operation of the missile assistant system. The action alternatives offered by the system remain unrestricted in the first place, i.e. the operator may carry out any desired low-level task at any time, allowing him/her to keep full control of the situation. With each step of the observed user interactions, the actual task can be narrowed down, depicted by the yellow dashed lines, allowing to guide the operator in finding the shortest command sequence to reach the designated work objective.

# 3 Missile Operator Assistant System

Fig. 4 depicts how the assistant system is embedded into the missile operator work system. To illustrate the difference to conventional automation being part of the operation-supporting means, the assistant system is placed next to the missile operator as part of the operating force.

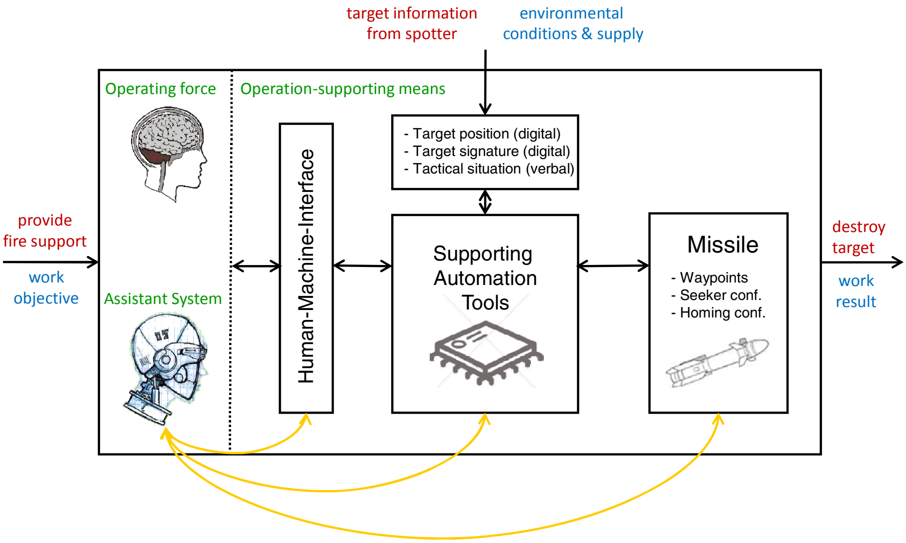


**Fig. 4.** Work System of Missile Operator and Assistant System

The assistant system's job can be compared to that of a co-pilot in an airplane: The co-pilot knows the current work objective, is aware of the environment and can exchange information with the pilot in command. Situational task demands, for example a request to change the landing runway, can force the pilot to hand over autopilot functions. Now, the co-pilot can assist by monitoring the pilot's actions and informing about faulty operation, making alternative proposals or even taking over control of the aircraft. Since a machine overtaking control from the human in a missile mission is undesirable due to ethical aspects, the proposed intervention level of the missile assistant system will be restricted to associative and alerting functions.

The supporting automation tools as part of the operation supporting means still exist to support carrying out closed tasks like automated route planning and flight duration calculations. Illustrated by the yellow arrows in Fig. 4, the assistant system can interact with the missile operator through the HMI. It also has access to the supporting automation tools to develop and present alternative action recommendations to the missile operator.

As described, the assistant system is based on recognizing the actual task by observing the operator's actions in a non-intrusive way. To be able to offer punctual and feasible support, a reliable estimation of the operator's objective has to be found as fast as possible. As described in [6], activity recognition in human computer interaction can be based on three main aspects: the *interaction set*, the *task model* and the *inference technique*.

The *interaction set* consists of the observed user interactions by the operator like keystrokes, mouse clicks and software events. Interactions can be embedded into the current context to increase the value of information. For example, the new position of a waypoint moved by the operator can be compared to the previous position to determine the most likely intention of the modification to the flight path. Moving and zooming the view can be interpreted as preparing changes either of the target configuration or the cruise flight path depending on the new visible view section.

The *task model* represents the sequential structure of a task. It can be generated by using task analysis tools (for example Hierarchical Task Analysis [7]) or by analysing the observed interaction sequences of test subjects during experiments. The resulting model should represent the optimal way to achieve the corresponding task, acting as a base for the supporting functions of the assistant system.

The *inference technique* links an observed interaction sequence with the task model [6]. A certain task can be achieved in various ways, using different available action alternatives or by altering the order of actions. The resulting, varying action sequences differ from the task model and can reduce the reliability of the intent recognition algorithm.

Commonly used predictive statistical models are presented in [8]. Hidden Markov Models have a rich history in sequence data modelling (for example in speech recognition systems [9]) and a promising approach for the missile operator assistant system.

At the time of identifying a matching task model, the assistant system can start to support the operator to achieve his/her objective. The implemented supporting functions include presenting single hints and alerts up to suggesting alternative action plans to the operator. The assistant system does not automatically execute or override any actions, because the operator should always be in charge of his own decisions. The resulting implemented *level of automation of decision and action selection* as defined by [4] ranges from level 1 ("The computer offers no assistance") in case of no deviations being detected between task model and human actions up to level 5 ("Executes […] suggestions if the human approves").

Additionally, based on the remaining uncertainty in identifying the correct task model, a higher level of automation could result in faulty decision support, corrupting the work of the operator. By restraining the maximum intervention level to 5, the operator can choose to ignore the proposed actions.

Possible supporting functions of the assistant system in the defined range can be

- informing about possible negative implications of the current task,
- highlighting the most imminent task,
- proposing pending tasks to reach the desired configuration with the option of automatic execution, and
- suggesting adjustments of already executed tasks to increase mission performance.

## 4 Experimental Method

At the UBM, a simulation environment for the introduced guided missile mission has been designed and implemented. The simulation allows human-in-the-loop experiments with test subjects, acting as missile operator. The operator can be confronted with different scenarios to force stressful, high workload situations as described above. After an incoming request for fire support, the planning phase begins. Now, the operator has to set up the missile configuration by planning the flight path, defining the target and configuring the final approach. The chosen configuration has to meet the following constraints:

- Limitation of flight duration and missile agility,
- time-over-target requirement,
- avoidance of terrain, structure and restricted areas, and
- ensuring the visibility of the target to the seeker during final approach.

Automation tools are implemented to support the missile operator by offering route planning, flight duration calculation and presenting information about violated constraints. After missile launch, the operator has to monitor the mission progress and wait for an incoming intervention request from the spotter. In the considered missile mission, possible requests can be

- mission abort,
- adjusting the time-over-target,
- modifying the final approach configuration (final leg length and approaching direction),
- switching to an alternative target, or
- updating the position of a moving target.

Each of the listed objectives requires the operator to execute a sequence of actions. As an example, to modify the approaching configuration, the operator has to move and zoom his view to be able to reach the corresponding waypoint. Additionally it may be necessary to adjust other cruise waypoints to avoid unfeasible or ineffective flight manoeuvres or to adjust the flight duration. Observable actions of the operator can be

- panning and zooming the map view,
- selecting an interaction mode,
- inserting, moving and deleting waypoints and
- setting and updating the target position.

The proposed missile operator assistant system based on intent recognition will be integrated into the simulation. By confronting the test subjects with various demanding scenarios, the resulting mission performance is analyzed while offering different types of supporting automation tools. It will be investigated if the assistant system can enhance the operator's performance in comparison to conventional automation.

## 5 Conclusion and Future Work

This paper introduces the design of a missile operator assistant system adapted to the special characteristics of controlling a short range missile with reconfiguring capabilities in flight. Pros and cons of integrating low and high levels of conventional automation support are described. The proposed assistant system acts on top of an environment of low level of automation allowing full control to the operator at any point in time. It is designed to adaptively support the operator in critical situations without requiring additional interaction steps. To offer reasonable support, the assistant system obtains knowledge about the current work objective by observing the operator's actions, inferring his/her most likely intention.

To examine the effectiveness of the proposed assistant system, a missile simulation environment is being developed at the UBM. A test subject acting as missile operator can be confronted with stressful, error-prone situations. Different types of supporting tools will be integrated to confirm the described negative effects of conventional automation. An assistant system based on non-intrusive intent recognition functionality will be implemented and evaluated.

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