Integrating Gaming Research and Practice in the Design of User Interfaces of (partly)-Autonomous Safety-Critical Systems

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ABSTRACT
Integrating more and more automation in systems is the classical approach followed by designers and engineers to support operators in the command and control tasks of more and more complex systems.

However, designing automation and designing interfaces for operating systems that are (partly) automated is a very complex activity altering in depth the development process of these systems. In the early days such automation was rather limited and thus easier to manage even though bad designs have been widely and frequently reported (e.g. [12, 15]).

Entertainment computing and gaming is a large research and industrial domain receiving an ever growing interest that has been facing such issues since the very first games. Early on games were involving autonomous objects and (later) automation-based tools for supporting (and evoking) extremely demanding and challenging cognitive, perceptive and motor activities.

This paper reports on work that has been carried out in the area of games and provides a set of design guidelines, processes and evaluation techniques applicable to the domain of safety-critical interactive command and control systems.

Keywords
Games, automation, user interaction, command and control.

INTRODUCTION
Automation is one of the main means for handling increasing complexity in systems. Indeed, automation makes it possible for designers to transfer the burden of operators to a system. Thus automation is having a strong impact on workload, team size and human error. However, together with this high potential, automation raises also complex issues at all the levels of the development process, from requirements to the very final validation and verification phases.

Command and control systems have to handle, in addition to the standard interactive objects, autonomous objects evolving in the same system but in a potentially complete independent manner.

In addition to that aspect, designers might want to empower the operators of such systems with (partly) automated tools in order to reduce users' workload and improve performance.

When designing user interfaces that deal with autonomous objects there are potentially two main problems that might be faced by the designer: (1) How the autonomous are represented in the user interface and how in general to design interfaces that enable the control of semi-autonomous objects. (2) How to design, develop, specify and evaluate user interfaces for command and control systems in which functions originally operated by a user are migrated into a partly autonomous system.

Automation has already been studied in a number of (sub-)disciplines and application fields: design, human factors, psychology, (software) engineering, aviation, health care, games [2] but the horizon for embedding them systematically into operational systems is not more than 10 years ahead. However, earlier adoptions of automation have not always been entirely successful as demonstrated by many studies in various application domains [12] or [15].

One distinguishing feature of the area of safety-critical systems is that system properties such as fault-tolerance, dependability or usability all have to be treated on an equal basis.

This paper focuses on two problem areas for the engineering of autonomous systems: first the engineering of the user interaction with autonomous systems (e.g. how to integrate autonomous behavior), especially in cases where autonomous objects are represented on the user interface. For example, the representation (on an air Traffic Controller screen) of an unmanned aerial vehicle (UAV) with which no direct interaction is possible, together with aircrafts with which interaction is possible via an interactive screen (and that information is sent to the pilots). Second the design and engineering of user interfaces and interaction techniques in general for (partly)-autonomous systems in charge of performing in an autonomous way tasks which we
Previously performed manually by operators. For instance, designing the user interface for an auto pilot in a plane or a cruise control must allow operators to set and/or control the auto pilot behavior.

**PROBLEM STATEMENT**

One of the current challenges and goals for autonomous behavior are related to the analysis, planning, decision and action cycle as described in [13]. When interacting with a (partly)-autonomous system the user interface and its underlying system should provide ways to support the operator in these activities. More precisely the operator should be supported:

- In analyzing the current context of the operations,
- In identifying one or several plans in order to carry on the current tasks or to handle unexpected events,
- In deciding amongst the various plans which one is the most appropriate,
- In inputting the plan into the system aspects such as reusing a previous entered plan or mending an existing one could significantly improve performance,
- In triggering the supervisory system to execute the plan which might include some degrees of autonomy (i.e. that the supervisory system has some delegated authority),
- In following the execution of the plan allowing the operator to know what has already been performed, what is the currently executed and what will be executed in the future steps.

Work has been done and is still in progress on authority sharing [4]. Of course the operator being in charge and responsible for the operations he/she should always have the possibility to interrupt the current plan.

One solution to that problem could be to reduce the operator role to the one of automation overseer and thus only acting at a high (and abstract) strategic level. Such solution would make it very difficult (and nearly impossible) for the operator to come back to a more low (and concrete) tactical level especially in case of automation degradation or system failure. Thus, other solutions have to be identified and designed requiring scientific means to assess:

- How the operator will be able to identify (from the currently available information about the autonomous system) new plans or modification to current potential plans (or potential configurations),
- How the operator will be able to build new plans or configurations,
- How the operator will be able to assess beforehand the impact of a potential new plan or configuration,
- How the operator will be able to interact (both monitor and possibly interrupt) with the current configuration under “execution”. This interaction aspect can be particularly complex if, in a proactive system, the configurations are executed in an autonomous way by the supervision system. Additionally such interaction should be conformant to the ones used for normal interactions.

As for solutions, one of the areas heavily using autonomous behavior is the area of games. Recent work in the area of games has shown that beyond simply doing a task, users want to engage with an interactive system, allowing them to have a playful and joyful experience [1]. User experience in games considers that the users should enjoy their activities while interacting with the computer and that this enjoyment can be one of the main goals they want to achieve.

**THE GAMING PERSPECTIVE**

In games the interaction is no longer only based on direct manipulation and input (i.e. the entire set of input is produced by the user having the entire initiative on the interaction), but gamers interact with a number of autonomous agents (e.g. non-player characters) that might (or sometimes not) be indirectly influenced and of which behavior is usually predefined but can be parameterized. Other interaction and usages include autonomous behaviors of game entities (e.g. for collecting resources in a game). There is a broad variety of ways to interact with these autonomous entities ranging from simple dialogue-based interaction to more complex interaction patterns, like position and movement of the (played) avatar, to influence the behavior of the NPC.

Additionally, in order to support players in their activities, repetitive, cumbersome or boring tasks can be usually automated allowing the player to focus and invest in more rewarding, fun ones.

While the application of gaming elements to the area of safety-critical systems might sound completely contradictory, there is a long tradition of applying simulation and game approaches by military commanders in their everyday planning activities [5]. Researchers in that area understood that it is of immense importance to use games in education or simulations [7].

**AUTOMATION IN GAMES**

We believe that the experiences in game design might help to find interaction solutions that allow displaying the critical information necessary for the operator to analyze, plan, decide and act. Additionally, games themselves could be used as a research platform to investigate usage of the systems, potential for errors and usability problems in the area of safety-critical systems.

Games offer a broad variety of interaction possibilities with autonomous objects. In the game community the development and representation of these autonomous objects is often based on what is called (by language misuse) “games artificial intelligence”. The term games artificial intelligence is abbreviated AI, but typically refers to the usage of scripts, multi-agent systems, agents or other algorithmic solutions that allow the programming of gaming elements that appear “intelligent” to the gamer. It must not
be confused with the term artificial intelligence (considered as a computer science sub-discipline), we thus use in the following the term game-AI.

In the following sections we will exemplify three different types of autonomous entities in games. These three levels would be good candidates for identifying desirable levels of automation and for identifying possible user interface and interaction techniques for interacting with objects of this type in a safety critical system.

**Full Initiative (Entity as Enemy - Fight)**

One of the game-AI approaches is a pattern-based technique that allows the entity to switch between a set of states: alert, patrol and idle. These states are triggered by the current state of the environment and, in order to support the player, are displayed using dedicated rendering techniques.

As an example of such an approach we use the game "Metal Gear Solid" [8] embedding guards as an example of autonomous entity. The behavior of a guard is rather simple, he is walking along a predetermined path, pausing sometimes to look around by sweeping the head and then continue his patrol. This type of autonomous behavior is called patrol-based games-AI [7]. The guard has sensory capabilities like eyesight and hearing.

To support playability, the visual detection capability is presented to the player as a line of sight (LOS). On the mini-map the LOS is a cone extending from the guard's eyes (see upper right corner of Figure 1). Similarly to the LOS, the hearing of a guard is represented by a circle surrounding his location.

![Figure 1. A security guard in Metal Gear Solid](image)

The security guard in Metal Gear Solid shows one of the possible solutions for how information about an autonomous entity can be presented to the player (or the user of the system). It corresponds to the case in which no direct interaction with the autonomous entity is allowed. In the gaming context this form of information presentation has been shown to work efficiently and effectively, allowing the user to understand the abilities and possibilities of the guard (i.e. the autonomous entity). It also supports the players’ activity of forecasting the future behavior of the entity.

**Mixed Initiative (Entity as Partner - Collaboration)**

A second example (see Figure 2) is the usage of direct interaction with the autonomous entity. To support better understanding of the player about the capabilities of the entity and how to interact with it such interaction is usually based on a metaphor-driven interaction.

As an example of such an approach, the game "Black and White" [3] is played from the perspective of the player being a god. The “god” player is graphically represented as a disembodied hand in the interface (see lower part of Figure 2). The “god” player is allowed to manage a unique creature that will serve as an assistant throughout the game. This creature (looking like a humanoid in the instance of the game presented in Figure 2) has its own behavior but can be allocated to tasks (destroying objects, collecting resources …). However, the creature has to be trained and its training has to be tuned on a regular basis. Training can be done by thanking the creature if it is behaving as expected (by scratching its belly with the “god” hand) or by punishing it (by slapping its face with the “god” hand). Doing so, the current state of the creature (corresponding to its future behavior) is presented to the user in a small cloud. In Figure 2 the creature helped automatically building and to thank it the player scratches its belly with the hand. As shown in the small cloud, the creature status for building has moved to the right (green part) meaning that now the creature is more likely to support the “god” player activity of construction.

![Figure 2. Interaction with creature in Black and White (the creature is now likely to help erecting buildings)](image)
Low Initiative (Entity as Slave - Tool)

A third example shows how indirect interaction with autonomous objects can be used. Games typically have ways that allow the player to manipulate entities considered as slaves and used as (partly)-autonomous entities.

An example of such entities is the “Probes” in the game StarCraft [16] that are a kind of collecting resources unit type. These probes have the ability to gather resources automatically, to teleport buildings etc. The player can influence these autonomous entities by selecting certain settings in a menu, which are then taken into account by the autonomous entity. Other possible interaction is the direct manipulation of the drone by, for instance, selecting the drone and then right-clicking on the type of resources the player wants it to collect. In Figure 3 a drone is selected and shows such a menu allowing to trigger an order to the probe that will perform it as a slave, until the resource is depleted, another order is triggered by the player, or the probe is destroyed.

Figure 3. Probes collecting resources in StarCraft

Such entities exhibiting low initiative could be easily used for performing repetitive operations that only require high-level monitoring from the operator. As they are present in a lot of games (especially the real time strategy ones) there have been many presentations and interaction techniques to allow players both to perceive the current plan of the entities (not in the case of StarCraft) and to interact with this plan.

A SAFETY-CRITICAL CASE STUDY

We recently started a joint-interest research activity with CNES and ruwido research to investigate how games approaches can be fruitfully applied to solve the problems of autonomous entities design and interaction. We identified the following set of issues that must be considered if the system is (partly)-autonomous:

- what is usability in a critical context and how to evaluate it;
- how to guarantee the safety and dependability of the possible interactions;
- how to design and specify interaction techniques where autonomous behavior from the system interfere with operator input (including the question on how to model that formally [6]);
- how to design interactions when the automation can fail and how to notify the operators;
- how to design interaction so that the operators can foresee the systems’ future steps and states;
- and how to enhance and evaluate aspects of user experience, while fulfilling the constraints of a safety-critical system which has to be secure, safe, reliable and usable.

We have applied the game approaches above to support the design and evaluation of user interfaces and interactions for safety critical (partly)-autonomous systems. This research work has started by establishing a classification of interaction possibilities that allow to support the interaction of users with (partly) autonomous objects and to establish new forms of user interaction that allow the control of autonomous objects. We do not present here such results due to space constraints but the final paper will present:

(1) How to apply game elements and aspects in safety-critical systems and how to apply them on the selected case study,

(2) Classification of interaction techniques and interaction concepts in games: Based on an extensive review of the games literatures as well as the topics on automation and interaction technologies in safety-critical systems a set of possible interaction concepts was identified,

(3) Development of a first conceptual prototype:

In the requirements specification phase we investigate how the conceptual prototype can be formally modeled including the interaction technology, answering the following questions:

- What gaming elements have to be considered which seem to be useful in that case study?
- How the conceptual prototype was specified (taking into account the safety-critical system)?
- How such a case study can be modeled using formal methods (including a brief presentation on how we model interaction technologies using formal methods in the area of safety-critical systems)?

The case study is based on a command and control system for drones as proposed in [6]. A screenshot of such interface (the paparazzi application) is given in Figure 4 where a group of three drones is managed at the same time. According to the classification above the drones in this application are similar to the probes in StarCraft and can be managed as slaves. In a broader context, and if considering the inclusion of such drones in an airspace, the other two types of entities have to be considered too. A completely independent entity could be a civil aircraft managed by a civil air traffic controller not reachable by the operator in
charge of the drone. Only the “callsign” of the aircrafts would appear on the radar interface with no possible interaction. Military aircrafts that might be involved in the mission might not be reachable directly by the operator but the operator might be able to interact with the pilots through the military Air Traffic Controller (ATCO) in charge of the airspace. In such a case, the operator can use the user interface to send requests to the ATCO that, in turn, will send them to the pilots.

Figure 4. A screenshot of the user interface for multiple drones (UAVs) management as described in [6]

CONCLUSION AND PERSPECTIVES
The research work presented here has been trying to bring together multiple disciplines for the design and evaluation of interactive systems with entities featuring heterogeneous levels of automation.

The abstract presented here has been focusing at the contribution from the games community and has presented how some of these contributions could be integrated in the design of a command and control for UAVs. The final paper will present in details how the games contributions can be classified and structured in order to provide generic design guidelines. We will also present how other properties such as dependability and fault-tolerance can be handled concurrently with usability. These contributions will be based on previous work presented in [10] and [9].

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