Human Autonomy Teaming using Cooperative Automation, Interaction Patterns and Image Schemes

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ABSTRACT

Human Autonomy Teaming needs clear patterns that can be understood by all human and machine team members in order to become really cooperative. The proposed contribution addresses this challenge by linking the paradigm of cooperative automation with interaction patterns and image schemes. Image schemes derived in psychology and describe the fundamental linking principles of human (embodied) cognition and the world. As an example, cooperative automation, interaction pattern and image schemes are applied to heavy military ground vehicles. Military vehicles like heavy trucks, tanks or excavators face the challenge of being sufficiently guarded against enemy fire and being safely manoeuvrable. The latter includes driving capability but also vision in order to see where the vehicle is driving. Current military vehicles therefore face a trade-off between optimal vision and optimal armour resulting in more obstruction of the driver's sight and the necessity of an assisting or automating co-driver when using a heavily armoured truck, tank or excavator. In order to overcome such limitations the human co-driver can be replaced by a cooperative automation that supports the driver in the driving tasks as an autonomous but cooperative team member in a cooperatively guided vehicle. To efficiently communicate information between co-automation and the crew, interaction patterns and AR was applied.

1.0 INTRODUCTION

Cooperation becomes necessary when two or more actors with the ability to autonomous behaviour are supposed to work towards a common goal. A successful cooperation is characterized by a consistent, commonly accepted result generated by the actors. If those actors do not work cooperatively, the best result would be two results and the worst none at all. Cooperation is not useful in all situations, e.g., in trivial tasks or tasks with a low resource demand, or in competitive circumstances. Still cooperation makes sense when several aspects of a task require a multiplicity of abilities or expertise like in interdisciplinary teams that work on complex tasks. Furthermore, cooperation makes sense, if the workload for a single actor gets too high and could be reduced by a better balance between several actors.

When talking about cooperative movement, the cooperation or collaboration of at least two actors with the goal of changing the current location is addressed. In Cooperative Guidance and Control a human operator works together with a cooperative automation, which we call co-automation or co-system. Cooperation is enabled by successful interaction. In our concept, interaction is facilitated using an Interaction Mediator [1] see Figure 1.

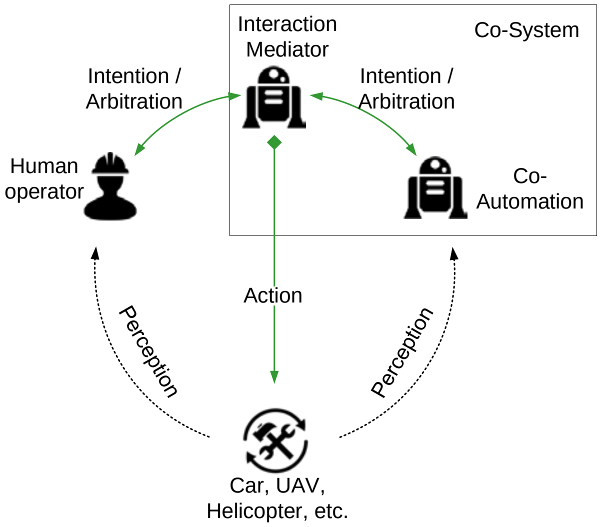

Figure 1: Cooperative Guidance and Control, cf. [2]

The automation of such a cooperatively guided manipulator, like e.g., a highly automated car, UAV or helicopter, can either assist the driver, e.g., to maintain an energy efficient state or even take over more advanced movement tasks such as lateral and longitudinal control in varying degrees [3]. In the military domain, these aspects can be extended with system qualities like safety and survivability. When driving for a certain time in a convoy, the workload of many drivers can be reduced to only the workload of the leading vehicle driver, where the others can observe the environment for threats.

1.1 Cooperative Automation

[4] already distinguished "Cooperation in action", cooperation in plan and meta-cooperation, which is not directly concerned by current control. Shared control seems to focus on the common task or function on the operational level, e.g. control, while cooperation adds the way to take increasingly into account the other agent and the other levels (see Figure 2).

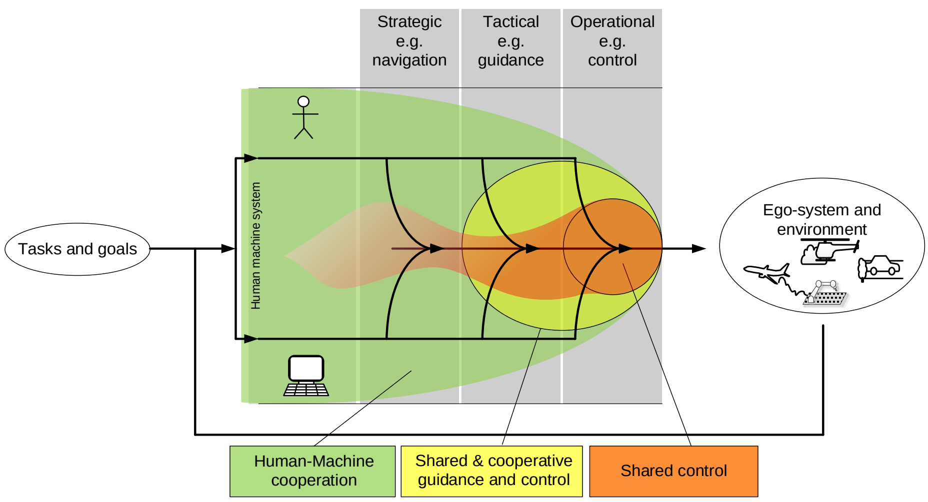

Figure 2: Relationship between the Shared control, shared and cooperative Guidance and

control, human-machine cooperation (cf. [5])

More than to know what the other is doing, cooperation allows to have a model of the partner to know how it is possible to cooperate with it/him/her. A cooperative agent (that has know-how-to-cooperate) can gather information about the other, analyse this information to decide about their cooperation. Such activity can again go directly back to the operational level, e.g., with shared control. But such cooperative activity can and should be prepared at the tactical and strategic levels.

An effective way to create cooperation between human and automation, is that human and machine have the same internal model of what has happened, what is currently happening and what will happen. This kind of compatible internal models is called cognitive or inner compatibility [6].

Known models to improve inner compatibility were proposed by [7], [8], [9], and [10], that distinguish navigation, guidance and control level of the driving task. [11] combined these to a simplified model of human information processing while guiding a vehicle with the guidance level split into long term (manoeuvre) and short term (trajectory) planning in order to enable technical realisation (see Figure 3).

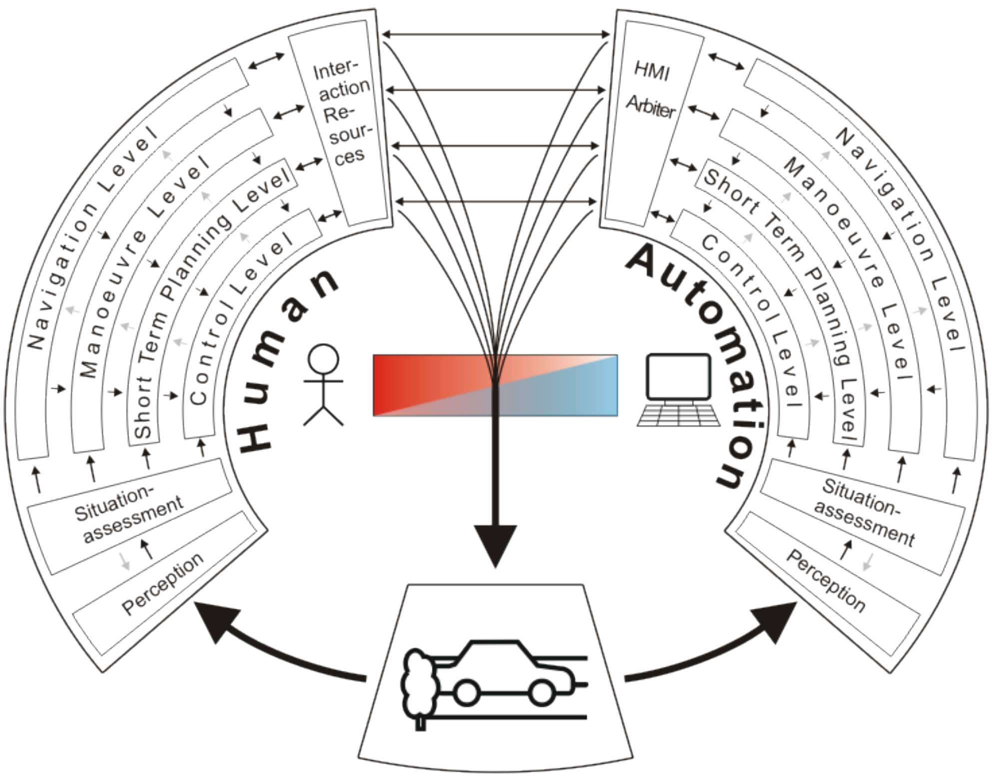

Figure 3: Human and Cooperative Automation (cf. [11])

In this model compatibility results from implementing the structure of human planning and acting into the automation. On the human side perception works over the sensory modalities, whereas the automation needs suitable sensors. Situation assessment is the interpretation of the situation and its projection into the future.

The planning phase can be differentiated into four levels: Navigation, representing the route through the road network; Manoeuvre, semantically determining what next manoeuvre to perform in order to comply to the route; Short term planning, to generate the trajectory that is according to the manoeuvre; Control, representing the specific commands (steer angle, gas) to conform with the respective trajectory. In order to generate common actions, the intention of human and machine need to be communicated and arbitrated via the interaction resources by the HMI Arbiter on all 4 levels. How these actions work is determined by the respective automation level.

The automation spectrum shows multiple possibilities of task distribution. Examples of mode configurations are seen in Figure 4.

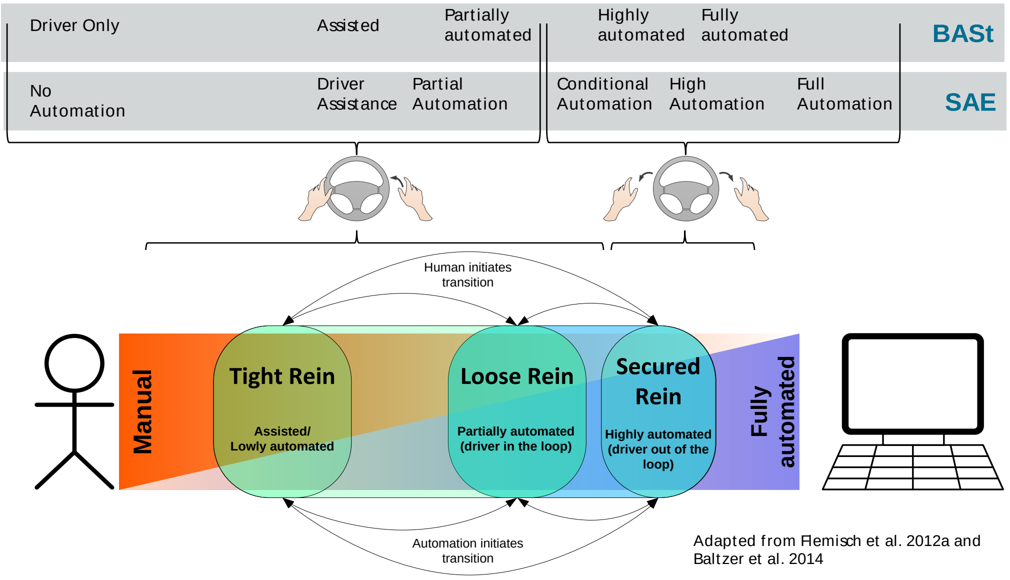

Figure 4: Possible Mode Configurations in Cooperative Guidance and Control (cf. [1])

As a means to create intuitive interaction between human and co-automation, the interaction mediator uses interaction patterns that will be explained in the following.

1.2 Interaction patterns for Cooperative Guidance and Control

Interaction patterns are solutions to recurring interaction problems described by their use cases. Interaction Patterns are described by the flow of information from the Source domain that results in the change of the user´s understanding of one of more internal target states (see Figure 5). These states can be e.g. an understanding of power or urgency. This flow of information can happen in many ways, we use image schemas to guide this information in a more natural way that can be related to previous embodied experiences.

Image Schemas originate from our experiences with humans, objects and events in our environment. When visiting restaurants for example we start to generalize things and develop abstract generic expectations about what we can expect from other restaurants. Therefore, when somebody tells us from their restaurant visit, we do not need to know all details like having paid etc., since we have our own schema of such a restaurant visit filling the missing information with our own experiences.

In another sense Image Schemas are not specific to a certain sensory modality [13], [14]. The so created ambiguity of being abstract (they are schematic) and not abstract (they are embodied) can be solved by understanding image schemas as abstract repeating representations of dynamic patterns of embodied interaction with our environment, that structure our understanding of how the world works. Their strength for human machine interaction design lies in their metaphorical extension (e.g., importance, power, etc.), so they can transmit more meaning than just affordances [15].

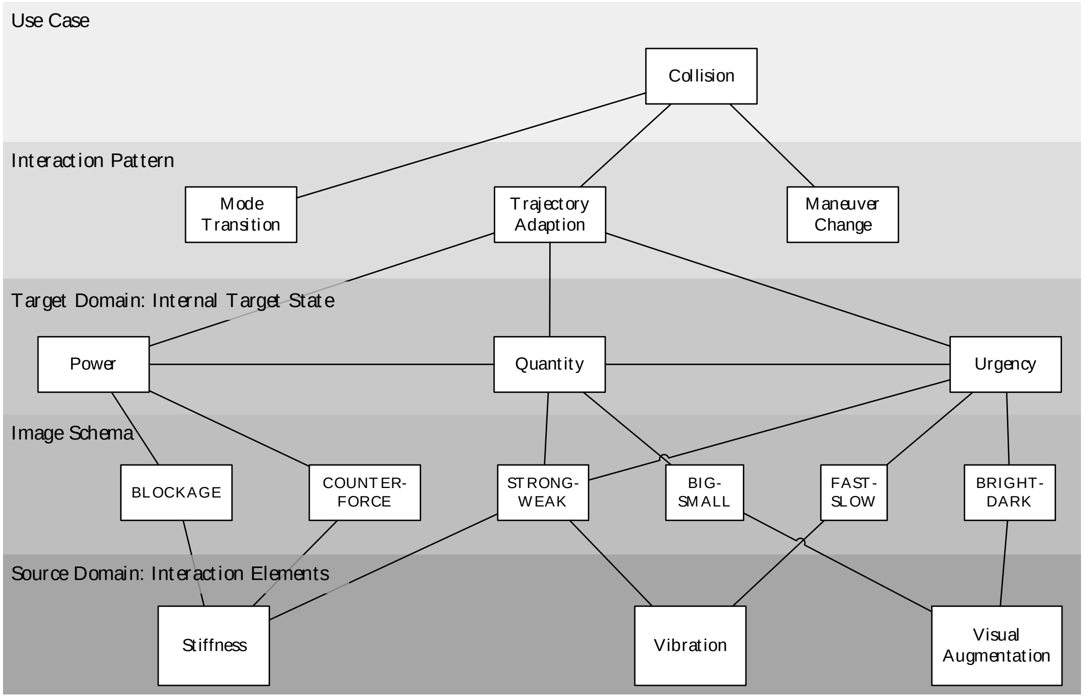

Figure 5: Information flow related to interaction patterns for Cooperative Guidance and Control (c.f. [12])

A simple example of an Image Schema is the CONTAINER schema that is built from the structural elements of an INTERIOR, a BOUNDARY and the EXTERIOR [16]. Human understand their body as a CONTAINER with their skin (BOUNDARY) delimiting their inner organs (INTERIOR) from the environment (EXTERIOR) [16]. This schema can be used for buildings, bottles and a Local Area Network. In terms of design they can be used to transfer meaning between the source domain, e.g., sensory modalities, and the target domain, e.g., speed of action, progress, importance or intensity.

Image Schemas work as a translation between specific bodily experiences from the source domain, i.e., via interaction elements and the abstract target domain, i.e., internal target states. Interaction elements can be described as implementations that generate a certain image schema, e.g., a large stiffness in the gas pedal creates the understanding of a BLOCKAGE etc.

Interaction patterns must have a solution: an actor reaction, this reaction can be an acknowledgement, a movement or a trigger for another action. The more obvious the actor´s reaction, the easier it is to see if a pattern works as intended.

An Implementation of such an interaction pattern is presented in the following section.

2.0 INTERACTION PATTERN "COLLISION AVOIDANCE"

2.1 Name

Collision Avoidance.

2.2 Problem description

The main problem addressed by the interaction pattern is to prevent collisions with objects in the vehicle's proximity. There are at least two tension poles from the perspective of the ego-system between which a balance needs to be achieved: approaching the obstacle(s) and keeping at distance of (or deviating around) the obstacle(s). The awareness might be low, perception might be reduced. The problem can be visualized, see Figure 6.

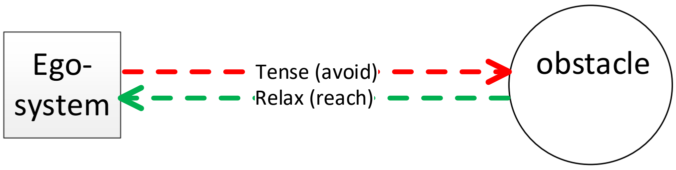

Figure 6: Abstract problem description for the interaction pattern "collision avoidance". Upper red arrow represents tensing action due to approaching the obstacle. Lower green arrow represents relaxing action due to receding from the obstacle. The balancing action is to avoid the obstacle and reach a safe distance (cf. [19]).

2.3 Solution

A stepwise escalation can lead to a higher awareness that the danger in the current situation is increasing when continuing with the current action or non-action. Also escalation offers the opportunity to react on user action, hence a positive reaction to behaviour adaption towards the non-danger tension pole. Depending on the relative speed and the escalation phase a respective obstacle avoidance manoeuvre should be chosen, e.g. an implemented automated lane change pattern or an implemented emergency brake pattern. To make both avail-able a mode transition pattern is necessary to decouple the driver.

The escalation should be triggered depending on the TTC in situations with rather high relative velocities, and triggered depending on distance in situations with rather low relative velocities. The result of the pattern implementation is an improved awareness of the target domains Variation and Importance. Variation of the current system state and Importance to change the current behaviour.

2.4 Consequences

The interaction pattern addresses a reduction in collisions with near objects and accordingly will reduce lateral displacement from the centre of the lane. Due to a reduced task load, the Situation Awareness of drivers will be enhanced. The solution focuses on adaption management, therefore certain internal target states, like Variation and Importance, are addressed. These domains are addressed, since an action needs to be made to avoid a dangerous situation that is going to happen in the current course of (non)action. Challenging consequences are the aspect of overtrust or overreliance in a non-perfect system. Also connected to non-perfect systems are wrong escalations due to falsely detected objects that may negatively affect acceptance. Finally an overreaction by the user could be observed when escalation phases are too small.

2.5 Implementation examples

The target domain of Variation can be addressed using the image schema PATH. Structural elements of PATH are a start, an end and a direction, [14] and [15]. The PATH schema also includes a series of locations [16] that can be interpreted as escalation steps. Symbolic qualities addressing Importance can be implemented with colour codes following the pattern from traffic lights, where red means stop or danger and green means go or safe [17]. These colour codes can be emphasized using the BRIGHT-DARK image schema [18].

The start and end locations or phase limits need to be determined with relevant variables. In a situation with rather high relative velocities, e.g. following a moving car, distance is not sufficient information to determine the need for behaviour adaptation. In situations with high relative velocities the need for reaction is farther away than in situations with low relative velocities. Therefore a combination of relative velocity and distance as time to collision (TTC) seems to be a valid concept to determine escalation boundaries in situations with rather high relative velocities. In more static situations, e.g. parking or slowly driving in a narrow road, the TTC becomes unfeasible due to extremely low relative velocities and the need for very close approaches, so that distance seems to be a useful concept in such situations. Another variable that takes the current driver's behaviour into account is the current steering angle. Therefore depending on the situation the same pattern can be used with different escalation variables and boundaries.

The respective implementations for a collision avoidance pattern in a situation with rather low relative velocities are visualized in Figure 7, for forward collisions, and Figure 8, for side collisions or road departure.

The PATH image schema is implemented having three distinctive steps or locations: Low urgency, medium urgency and high urgency. The respective variable when a certain urgency level is reached depends on the distance between the ego vehicles bounding box and the obstacle's bounding box as well as the current steering angle. Depending on the ego vehicle's action a Variation of Importance is defined by the escalation phase.

In Figure 7, we see the implementation of the collision avoidance pattern in a forward collision avoidance assistance when approaching a parked truck.

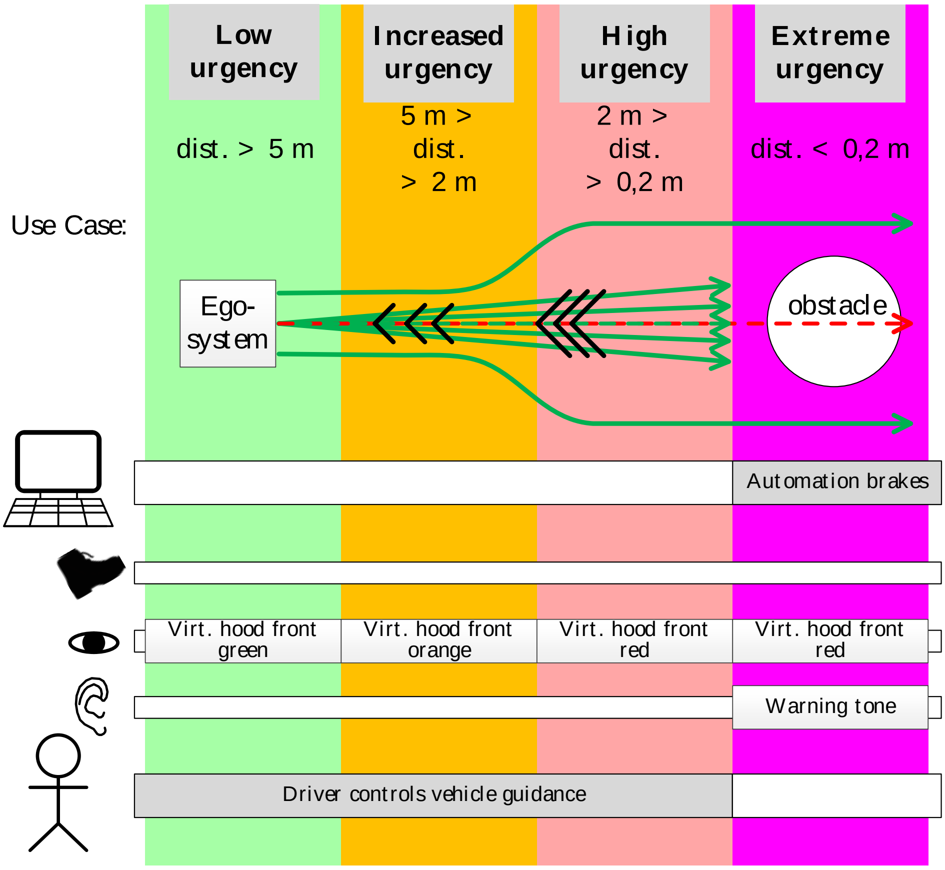

Figure 7: "Collision Avoidance Pattern" to prevent collisions in forward vicinity (cf. [19]).

When there is 5 m distance between ego-vehicle and obstacle the forward hood turns from green to orange, except if the driver starts to steer to the right. When forward distance is lower than 2 m and the ego vehicle and obstacle are in the same lane, forward hood turns from orange to red except if the driver starts to steer to the right. If the driver initiates reverse and the distance increases the interaction pattern deescalates, respectively.

A similar collision avoidance pattern can be implemented to be used as a side collision avoidance assistance either for parked vehicles at the side or to prevent road departure (see Figure 8).

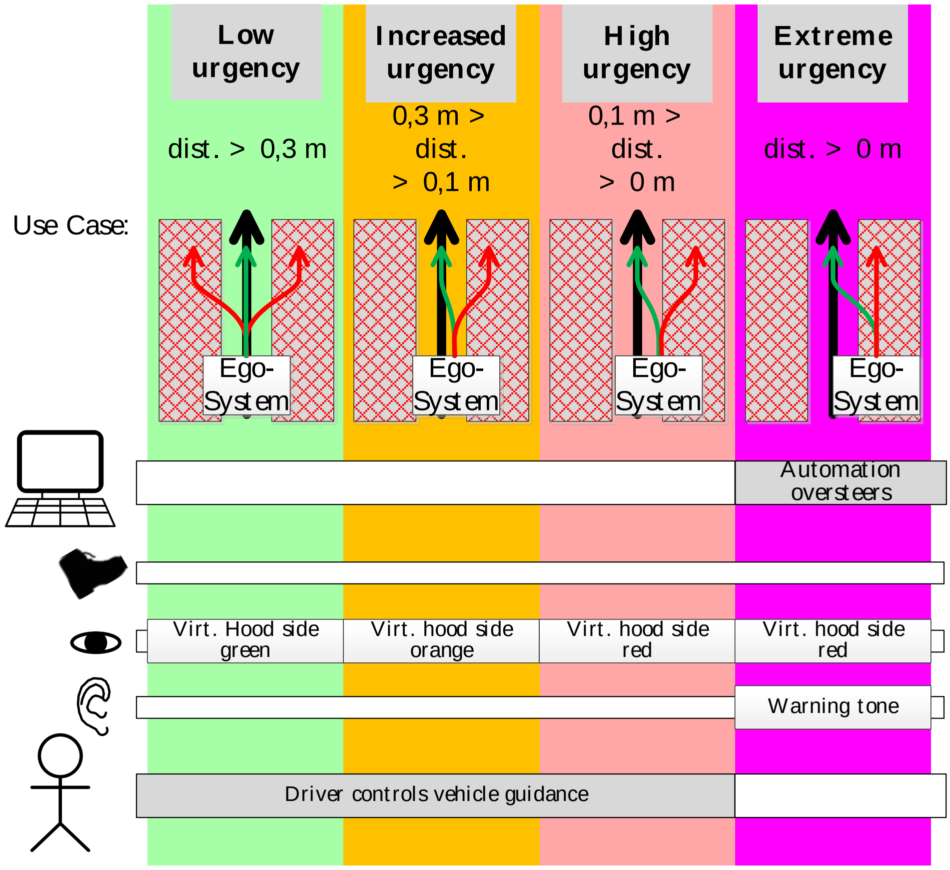

Figure 8: "Collision Avoidance Pattern" to prevent side collisions or behave like a virtual gravel trap when departing from a road (cf. [19]).

Again not only the current relation of the vehicle towards a side obstacle or road-side end defines the escalation, but also the driver's action. If the driver already steers to the left when departing to the right, the pattern will deescalate according to the steering model of the vehicle and the respective time of lane departure (TLC).

3.0 STUDY

To test the collision avoidance interaction pattern for different system qualities, different scenarios were used.

3.1 Study design

The design of the experiment was a within subjects design with three repeated measurements. 18 military drivers took part. The mean age of the participants was 32 (SD=6,3). Every run included a training of 3 minutes to get used to the setup. After every condition they filled out the NASA-TLX questionnaire. At the end of the experiment the systems were evaluated in a semi-structured interview.

The NASA Task Load Index (NASA-TLX) [20] is an assessment tool that rates perceived task load in order to assess a task. The task load is divided into six subscales. They are rated for each task within a 100-points range with 5-point steps.

- Mental Demand: How mentally demanding was the task?
- Physical Demand: How physically demanding was the task?
- Temporal Demand: How hurried or rushed was the pace of the task?
- Performance: How successful were you in accomplishing what you were asked to do?
- Effort: How hard did you have to work to accomplish your level of performance?
- Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?

Additionally quantitative data for displacement of the centre of the lane and the amount of collisions with infrastructure, cars and mines was logged during the test runs. Different scenarios were used to find out about the usefulness of the different test conditions in terms of performance and situation awareness (driving data), and task load (NASA-TLX). The respective scenarios were a city scenario with other traffic participants, like pedestrians and other vehicles, and an off-road part. In order to prevent sequence effects, two different maps with different scenario sequences were built and the test conditions permutated.

Respectively, comparable interaction patterns were used in the off-road part, where a very narrow path needed to be followed through a mine field.

3.2 Setup

The participants drove in a random order with a cabin, a monitor and a monitorsystem with augmentation condition (see Figure 9).

The study was conducted in a generic static driving simulator running the professional driving simulation software SILAB from the Würzburger Institut für Verkehrswissenschaften. As driving interfaces an active steering wheel and active gas and brake pedals from the company SENSODRIVE were used and a Sidestick from the company Stirling Dynamics as gear stick.

Regarding the visual interfaces, there was a training condition and three test conditions (see Figure 9).

In the training condition Figure 9 a) the simulation was visualized via a cave set-up representing three large projection screens that were arranged in a 90 degree angle to the sides and to the front. Additionally two 13” LCD 720p monitors were used as rear-view mirrors. A third 13” LCD 720p monitor was used to visualize speedometer and tachometer.

In the cabin condition Figure 9 b) a wooden vehicle frame was added to the training condition to introduce ambient occlusion at A and B-pillars.

a) Training **b) Cabin** **c) Monitorsystem**

d) Monitorsystem with interaction pattern

Figure 9: Training and test conditions during the experiments

In the monitor condition Figure 9 c) and d), the wooden frame was replaced by a monitor array of five 13” LCD 720p monitors that cover 160 degree of the driver’s horizontal field of view. Rear-view mirrors as well as ramp mirrors were integrated as picture-in picture (PiP) in the forward left and forward right screens (see Figure 9 d)).

Additionally in the monitorsystem with augmentation condition Figure 9 d) de-pending on the actions of the driver and the respective situation, interaction pat-terns escalated or deescalated. As mentioned before, the basic architecture of the generic assistance and automation system is based on the concept of interaction mediation and cooperative guidance and control of highly automated vehicles [1], [3]. In the respective study only visual assistance is given via the screens. Therefore the final escalation step of the collision avoidance patterns Figure 7 and Figure 8, when control was shifted from human to automation, was not considered.

The hypothesis of this study is that the human behaviour adaptation using interaction patterns via a camera monitorsystem with augmentation will improve the situation awareness, the driver performance and will reduce the overall task load.

3.3 Evaluation

As mentioned before, the concepts were tested in a simulator experiment, in which 18 military drivers took part. The mean age of the participants was 32 (SD=6,3). All of them have a car and a truck driving licence, eight a motorcycle licence, and three a tank licence. 11 of the participants use their vehicle for pri-vate purpose daily, 1 participant 3-5 times a week. 50 % of the participants had very little simulator experience, 50 % little or rather little. Eleven persons asses their driving style as safe/experienced, three as dynamic/sportive/brisk, 4 as cautious. The experience with driving assistance systems, e.g. lane departure warning system, was very low. Only with adaptive cruise control systems 50 % of the par-ticipants have extensive experience.

Figure 10 and Table 1 show the results of the NASA-TLX

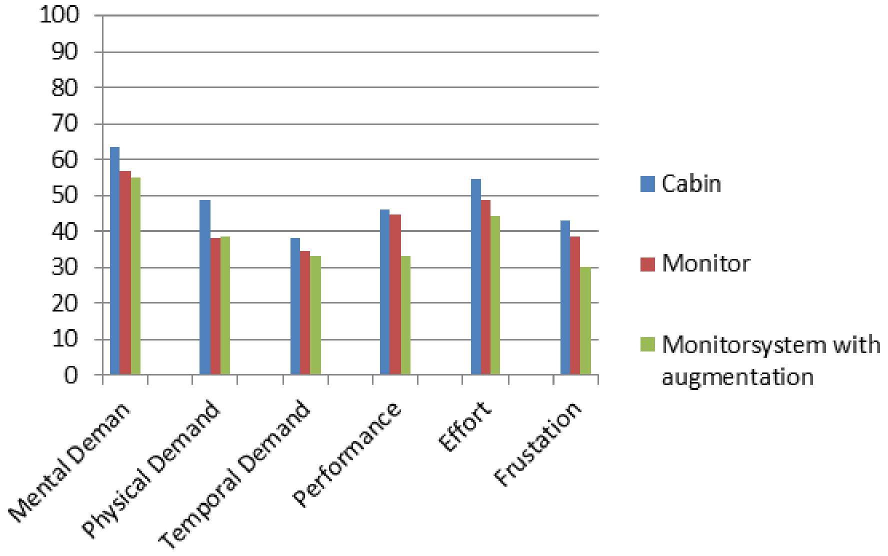

Figure 10: NASA-TLX diagram.

Table 1: NASA TLX Scores.

	Cabin M (SD)	Monitor M (SD)	Monitorsystem with augmentation M (SD)
Mental Demand	63,33 (25,95)	56,94 (24,20)	55 (23,31)
Physical Demand	48,61 (21,13)	38,06 (18,16)	38,61 (21,41)
Temporal Demand	38,33 (18,15)	34,72 (20,11)	33,06 (15,54)
Performance	**46,11* (19,52)**	**44,72* (19,89)**	**33,33* (14,65)**
Effort	54,72 (23,29)	48,61 (25,19)	44,44 (24,85)
Frustration	43,06 (20,23)	38,61 (23,06)	30,28 (18,90)

*p<0,05

The mental demand for driving with the cabin was higher rated than when driving with the monitor and monitorsystem with augmentation condition. The physical demand was also rated as the highest between the concepts. The monitorsystem with augmentation had the lowest temporal demand, effort and frustration. The participants were satisfied with their performance the most after driving the monitorsystem with augmentation. For the performance there was a statistically significant difference between all conditions. A repeated measures ANOVA showed a difference, $F(2, 34) = 7{,}055$ $p = .003$, partial $\eta^2 = .293$. A Bonferroni-corrected post-hoc test showed a significant difference between the cabin and the monitor condition (.009, 95%-CI[-22.63, -2.93]). Also there was a difference between the monitor and the monitorsystem with augmentation condition (.005, 95%-CI[-19.45, -3.3]).

The results from lateral displacement from the road centre are displayed in Figure 11 and Table 2.

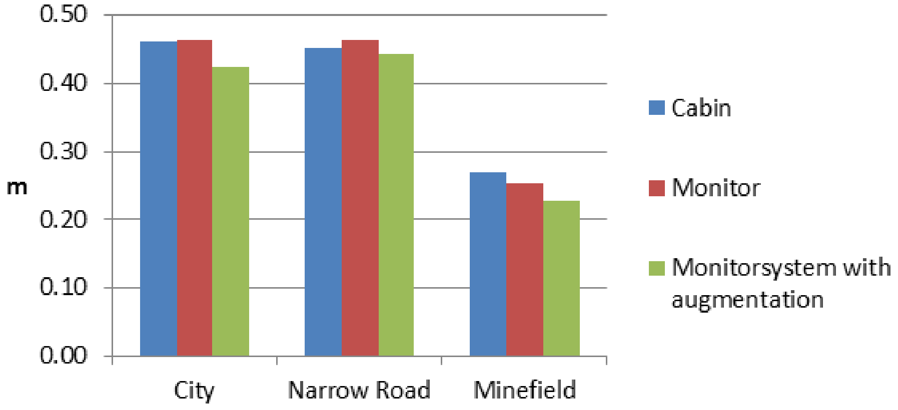

Figure 11: Displacement from the centre of the lane.

Table 2. Displacement from the centre of the lane.

	Cabin	Monitor	Monitorsystem with augmentation
	M (SD)	*M (SD)*	*M (SD)*
City	0,46 (0,14)	0,46 (0,12)	0,42 (0,16)
Narrow road	0,45 (0,07)	0,46 (0,09)	0,44 (0,09)
Minefield	0,27 (0,11)	0,25 (0,09)	0,23 (0,09)

The lowest lateral displacement was in all parts of the scenarios with the monitorsystem with augmentation. A statistical significance could not be found between the conditions.

In Figure 12, Figure 13 and Figure 14 show the different amount of collisions with the respective elements. Collisions with infrastructure, cars and mines were mainly caused in the cabin. The probability of a collision is higher, but also the amount of absolute collisions. The infrastructure used in this study was made of houses, walls, traffic lights and traffic signs.

Figure 12: Collisions with infrastructure.

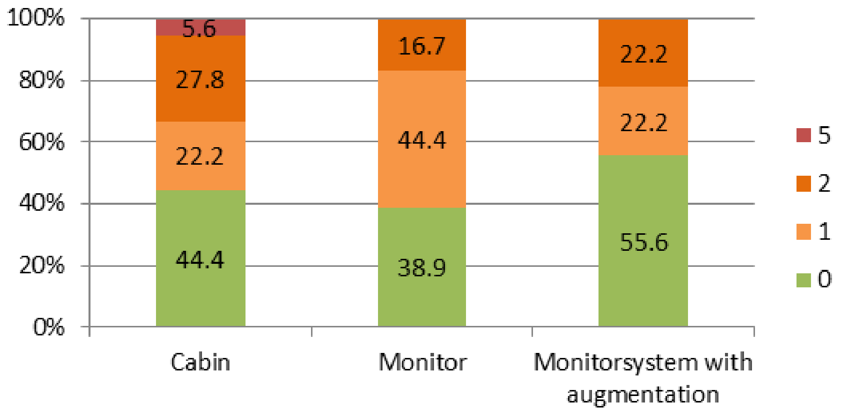

Figure 13: Collisions with cars.

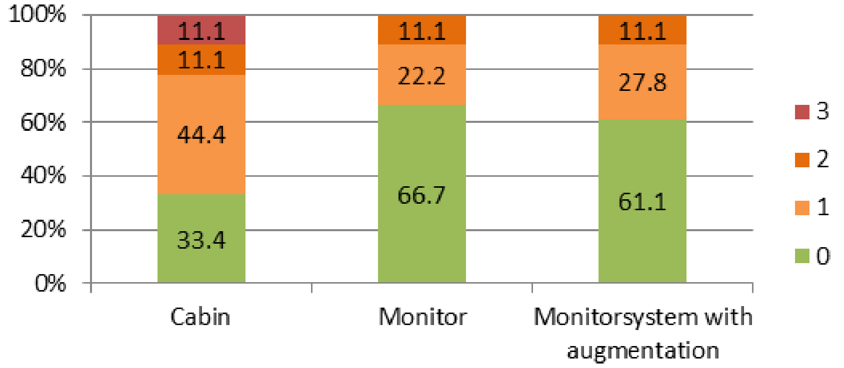

Figure 14: Collisions with mines.

4.0 CONCLUSION AND OUTLOOK

This publication described how interaction patterns and image schemas could be used in Human Autonomy Teams with a cooperative automation. This approach was developed in close interplay with the concepts of cooperative guidance and control, where a cooperative automation and a human control a machine together, and of augmented reality, where a natural representation of the world, e.g. in form of a video stream, is enriched with dynamic symbology. The concept was applied to armoured vehicles, instantiated as interaction pattern "collision avoidance", implemented in a fix based simulator, and tested with professional operators. The results were a good mix of encouragement and lessons learned, both for the methodical approach of pattern based human machine interaction, and for the application of AR-based cooperative guidance and control.

The use of interaction patterns for collision avoidance, which was tested in the study, showed different aspects of improvement. One of the main objectives to reduce the number of collisions with vehicles in the near proximity could be reached. Also the displacement was always lower. As a result the driving performance could be enhanced. Furthermore the task load could be reduced, as the driving with the augmentation caused the lowest temporal demand, effort and frustration. Also the participants were satisfied with their performance the most.

A possible opportunity for improvement is the integration of live eye tracking to move the drivers focus e.g. from one screen to another or to point out the critical collision area. Physiological metrics might be useful for patterns in other situations, e.g. combining higher assistance and automation degrees with a mode transition pattern when the task load of drivers is too high. Also the used visual figure of the hood could be improved in terms of size and form. Additionally multimodal extension of the patterns with haptic or acoustic feedback could be evaluated.

Regarding the AR-based cooperative guidance and control: We gained an increasing understanding of how this cooperative interplay between an automation and humans can be organized, and patterns are an excellent way to describe this organization. We have encouraging results on a couple of patterns, and especially with the link to image schemas we increasingly understand why some patterns work differently and better than others. With all optimism, we are far from having optimal patterns, and far from having more than a first glimpse of this vast design space of human machine cooperation, and technology based reality augmentation.

Regarding the overall approach of linking patterns with image schemas: For us this is the most promising way to link everything that the community has learned already about specific patterns and specific image schemas, and to make this available in the design process. We have a first understanding how this link can be done, however we are far from having an optimal way to do this linking of patterns and image schemas efficiently. More research, and especially more joint effort is needed to organize and combine the increasing knowledge that is being built up in different spots in the community, and to make this available in the specific design and engineering situation of real products, so that it can improve the increasingly complex human machine systems, not only in the far future, but right here, right now.

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Using Interaction patterns is the most promising way to link everything that the community has learned already about human autonomy teaming. Specific patterns and specific image schemas have to be tailored together, linked to specific tasks, and to be made available in the design process as early as possible. We have a first understanding how this link can be done, however we are far from having an optimal way to do this linking of patterns and image schemas efficiently. More research, and especially more joint effort is needed to organize and combine the increasing knowledge that is being built up in different spots in the community, and to make this available in the specific design and engineering situation of real products, so that it can improve the increasingly complex human machine systems.

5.0 ACKNOWLEDGEMENTS

Contents of this work were gained from studies funded by the German Federal Ministry of Defence and the Deutsche Forschungsgesellschaft DFG.

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