Mode Awareness Interfaces in Automated Vehicles, Robotics, and Aviation: A Literature Review

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ABSTRACT

With increasing automation capabilities and a push towards full automation in vehicles, mode awareness, i.e., the driver's awareness of the vehicle's current automation mode, becomes an important factor. While issues surrounding mode awareness are known, research concerning and design towards mode awareness appears to not yet be a focal point in the automated driving domain. In this paper, we provide a state-of-the art on mode awareness from the related domains of automated driving, aviation, and Human-Robot Interaction. We present a summary of existing mode awareness interface solutions as well as existing techniques and recognized gaps concerning mode awareness. We found that existing interfaces are often simple, sometimes outdated, yet are difficult to meaningfully expand without overloading the user. We also found predictive approaches as a promising strategy to lessen the need for mode awareness via separate indicators.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**; **Interactive systems and tools**.

KEYWORDS

automated driving, human-robot interaction, aviation, mode awareness, mode confusion, systematic literature review

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1 INTRODUCTION

Automated driving operates on a range of different vehicle automation capability, usually described via levels of automation [75]. Thus, vehicle automation is not a question of whether the vehicle is automated or not but to which degree the vehicle is automated, i.e., which driving tasks can the vehicle perform on its own and which are left to the human driver to perform. This more nuanced understanding of vehicle automation is not always reflected in public discourse and the resulting public's understanding of vehicle automation [67]. Said public, however, are those who constitute the primary user base of vehicle automation technology.

As past incidents involving automated vehicles (AV) have tragically demonstrated [63, 83], correctly assessing a vehicle's capabilities and calibrating one's awareness accordingly can be vital to safely operating AV. We refer to interfaces or interface elements that serve this purpose of making the vehicle user aware of the vehicle's current mode of automation or overall automation capabilities as *mode awareness* interfaces. A mode awareness interface can range from a simple binary indicator, which shows whether whichever automation capabilities the vehicle is equipped with, to more detailed information about what the vehicle can (or cannot) do and/or what the driver's duties are at (e.g., "Hands on the wheel.") at any given time.

Considering the importance of appropriately communicating the automation mode in AV, the topic area appears underresearched and lacks a common basis of what exactly constitutes a mode awareness display as well as which methods and techniques work better for mode awareness displays than others. With this paper, we intend to provide such a basis via a literature review of existing works containing mode awareness interfaces as well as evaluations of the quality of these interfaces.

We extend the literature review beyond AV and into aviation and Human-Robot Interaction (HRI) as well. The reason for this is that both domains deal with automation technologies, where communicating the state and/or degree of automation is expected to play an important role when interacting with said technologies.

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We intend to draw from all three domains and gather information on currently existing solutions, information on whether or how well these solutions work (if available) and identify gaps regarding mode awareness communication interfaces or research related to such interfaces. More specifically, we address the following research goals:

- identify working best practices to be adapted for mode awareness automated vehicles
- identify research/development gaps in need of solutions or improvements

In the following, we will provide an overview of related approaches and then describe the sources and method used for conducting the review in this paper. We then provide a list of the final papers included in the analysis, as well as a thematic clustering and description of the papers' contents. We conclude with a discussion of the findings, identified solutions as well as gaps, and conclude with an overall summary at the end.

2 METHOD

For this literature review, we followed the approach by Okoli and Schabram [72]. The focus was on academic written publications only and the review does not cover public demonstrators, manuals, patents, news articles, or similar. In addition, only full paper publications and similar (conference papers, bookchapters, etc.) were included in the review; workshops, position papers, works in progress, theses and similar were excluded from the review. The publication research was conducted online via Google Scholar, IEEEXplore, ScienceDirect, and the ACM Digital Library. No other sources, offline or online, were consulted for this research.

Based on the goals outlined in the previous section, we formulated the following concrete **research questions**:

- What are the current interface approaches to display the automation in automated driving, aviation and HRI?
- Which techniques and methods are known or used for improving the user's mode awareness in these domains?

The purpose of the review was to find literature on displaying mode awareness across three domains. Thus, we conducted each search with a set terms related to mode awareness and additional sets of terms to indicate the specific area or sub-domain. The following is the list of terms and operators used for each domain:

- **Automated Driving:** ("mode awareness" OR "mode confusion" OR "mode errors") AND ("automated vehicles" OR "automated driving") AND ("driving modes" OR "modes of automation" OR"levels of automation" OR "driving levels")
- **Human-Robot Interaction:** ("mode awareness" OR "mode confusion" OR "mode errors") AND ("HRI" OR "human-robot interaction" or "human-robot collaboration")
- **Aviation:** ("mode awareness" OR "mode confusion" OR "mode errors" OR "state awareness") AND ("automation modes" OR "auto-flight mode" OR "autopilot" OR "flight mode") AND ("aircraft" OR "aviation")

The term "state awareness" was added to aviation, as it had been identified in the preparatory state-of-the-art analysis as a commonly used synonym for "mode awareness" specifically within the aviation domain. As this research is intended to focus on mode awareness interfaces in particular, we did not extend the search to general literature on control transitions or take-over procedures. For a literature review on control transition interfaces in AD, see Mirnig et al. [66]. We set the search to go as far back as 2011, as 2010 had seen a strong increase in industrial robotics. Works on automated driving started to mainly appear around 2014 but we set the same cut-off year for all domains for consistency. The search across all repositories yielded, excluding duplicates, 116 results for AD, 247 for HRI, and 688 for Aviation, for a total of 1051 results across all three domains.

Table 1: Overview of publications per domain from the initial search and after each round of screening.

	AD	HRI	AV	Total
Initial search	116	247	688	1051
1st screening	79	191	301	571
2nd screening	42	16	45	103

The screening of publications proceeded in two stages according to a pre-defined protocol, followed by the analysis. The main goal for each of the initial two stages was to identify every publication's relevance regarding the two primary research goals, namely:

- Does the publication include a description or illustration of a mode awareness interface?
- Does the publication include information on methods, techniques, or gaps regarding mode awareness?

If at least one of these selection criteria was found to be fulfilled, then the publication was included for the next round.

The *first round of screening* was performed by two researchers independently. In this round, all publications' titles, abstracts, and keywords were screened with regard to the two selection criteria. At the end, both screening results were combined into one, following a discussion and consolidation of deviations in the individual screenings. In cases of doubt, publications were included for the next round instead of excluded at this stage. After the initial screening, 571 publications across all three domains remained.

The *second round of screening* was again performed by two researchers independently. It involved reading Introduction, Results, and Conclusion of each publication as well as a scan of the Setup (if any) as well as figures and tables with regard to the two selection criteria. At the end of the second round, the individual results were again consolidated into a single list of publications. All publications that remained after the second round of screening (103 total) were included in the subsequent analysis. An overview of all publications initially found and after each round of screening can be found in Table 1.

The *analysis* was performed by one researcher initially and verified by the second researcher afterwards. This step consisted in a full reading of every single of the papers remaining after the second round of screening. The papers were analyzed in accordance with the research goals and based on the following working definitions:

- **Mode awareness interfaces:** Any image or verbal description of an interface solution to signal the system's mode of automation. E.g., an image showing a display in the cockpit of an airplane with "Autopilot on" would fall under this category.

- **Methods and techniques** Any method to assess the effectiveness of an interface to regarding mode awareness or any technique to foster mode awareness (e.g., design principles).
- **Gaps** Any statements regarding the lack of mode awareness interfaces within the respective domain, lack of features or effectiveness of existing mode awareness interfaces, and statements regarding the consequences of insufficient mode awareness within the domain.

Focusing on these aspects allowed us to extract existing interface approaches, information regarding the quality and assessment of these existing solutions, together with additional information what existing mode awareness interface solutions can and cannot do, where improvements are needed, and where such interfaces might be needed but do not yet exist at all. The paper contents were extracted and collected for each domain separately. They were clustered within each domain under the three categories *mode awareness interfaces*, *methods and techniques*, and *gaps* and then summarized into thematic sub-clusters. We present these results in the following section.

3 RESULTS

We present the findings from the literature review in a separate section for each research goal (interfaces, gaps, methods and techniques). The findings are clustered thematically instead of per domain. The domain relevance (i.e., in which of the three domains relevant literature was found) is written in brackets at the end of each thematic cluster title. We refer to Aviation with 'AV' in accordance with 'AD' and 'HRI' for the other two domains. A numeric overview of the clustered results can be found in Table 2.

4 MODE AWARENESS INTERFACES

In this section, different interface approaches to support mode awareness are presented. As most of the applications are visual indicators, there are some complementary solutions for them in the form of different feedback modalities. Also, as indicators (FMAs) are already used in AV, some approaches in the field aims to enhance the existing solutions with simple modifications.

Figure 1: Mode information shown on instrument cluster with a verbal indicator "Automation assistant is active" [32].

4.1 Verbal Indicators (AD, HRI, AV)

In the domains of AD and AVI, mode information is most commonly presented with verbal indicators on a display [2, 12, 31, 32, 44, 53, 59, 61, 71, 87, 88, 91, 94]. In the field of HRI, interfaces are used when the robot and human are located in different environments, such as in the cases of collaboration between human and a rescue robots [64, 65, 85]. Even though, using verbal indicators is a common approach, there is no common terminology for stating modes. In AD domain, terms such as "assist", "auto" and "manual" are used (Figure 1) to indicate different levels of automation [32, 33] and similarly in AV, "autopilot" [46] (Figure 2) is used. On the other hand, in the domain of HRI several different terms are used to state automation such as "inspection", "supervised", "supervisory" and "autonomous mode" [19, 55, 93] (Figure 3).

Figure 2: Mode information verbally stated on the top left on a display in AV [92].

4.2 Graphics/Icons/Symbols (AD, HRI, AV)

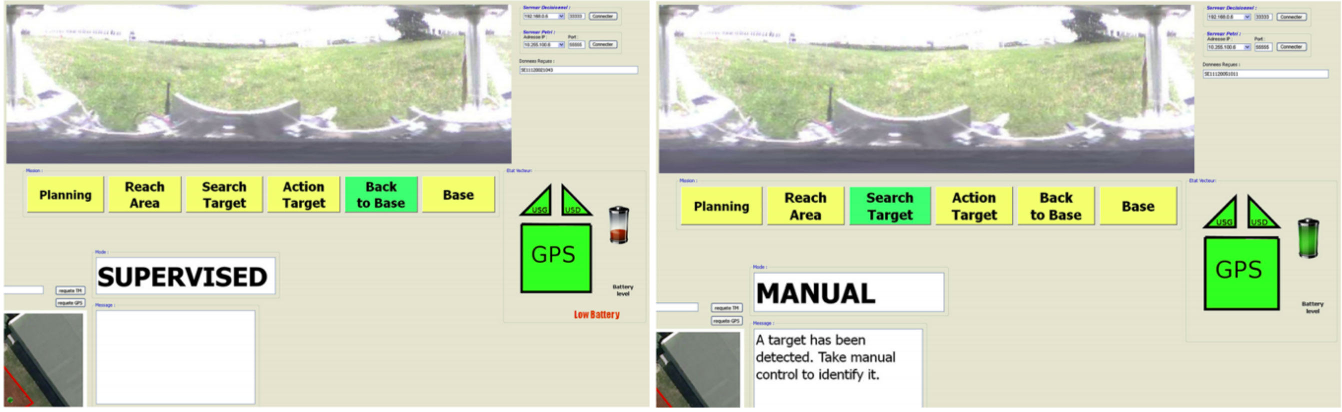
Together or stand alone, second strongest trend in all domains is to use of graphics, icons and symbols to indicate the mode, responsibilities of the driver and capabilities of system. Especially in AD, representation of what driver should do both with text and graphics are a common way for communicating the information [3, 26, 27, 36, 44, 46, 54, 71, 80, 86, 89, 94], similarly, in Aviation and HRI to support the textual information, graphics, icons and symbols are used often [12, 79, 91, 92].

4.3 Eye Catching Elements (AD, HRI, AV)

Apart from text and graphical elements, eye catching elements are used to draw the attention of the user, especially in critical situations. These are flashing of icons or light [15, 19, 32, 37, 79, 86], animation of visuals [53], pop-up displays [17] and exclamation mark at the of sentences [2, 36, 44]. Also change of color, especially red to draw immediate attention [61, 65] is a common approach to draw attention in all three domains [2, 3, 13, 26, 27, 33, 36, 44, 89].

4.4 Multi-modal Feedback (AD, HRI, AV):

Different modalities of feedback is often used as support to visual indicators. Most commonly, audio alerts are used in all domains [10, 52, 71, 84]. However, due to the loud environmental conditions in AV, this is used only in critical situations. In AD, there are several examples of different types and combinations of feedback. Some



SUPERVISED

Low Battery

MANUAL

A target has been detected. Take manual control to identify it.

Figure 3: An example from the domain of HRI where mode information is stated as "supervised" or "manual"[19].

examples include, haptic feedback applications on steering wheel or seat [8, 49, 74, 94], usage of light as complementary to visual interfaces [10, 32, 79], roll and pitch motion feedback [13, 14] and even scent feedback using olfactory displays [89]. In HRI, when there is a close collaboration between humans and robots, the mode indicators are in the form of physical buttons together with light feedback [37, 38].

Other solutions where there is a close contact is to use simple buttons combined with a color to convey the message to on and off [37, 38, 85]. Using a physical button to visually show the on and off of a certain mode, is was also used in as a solution to improve mode awareness in AD [84].

4.5 Providing the Details of The Mode (AD, HRI, AV)

Another strategy is to provide additional information that might contribute to the awareness of the user. In this sense, a common information for AD and AV is the vehicle speed [2, 80], and for AD and HRI, information on actions that needs to be taken by the user [12, 17, 19].

4.6 Additional Display Units (AD, AV)

Another approach is to add an additional display units such as HUD displays [33, 74, 94] or augmented displays [59, 94]. An example from AV is adding an additional display screen to the flight desk Extra Automation does what? (ADW) display [69] aiming to only show behavior of auto-flight not the mode information which is still shown on another screen and also an "Automation function configuration display (AFC) that provides awareness for normal and abnormal behavior of the automation [30].

4.7 Playing Around with Information Locations (AD, AV)

Moving the mode information to different display units is another approach to improve mode awareness.In AV, for example displaying the mode alerts on Engine-indicating and crew-alerting system (EICAS) [31, 61], on Flight management system or on navigation display [31] are tested. One of the examples include moving Flight Mode Annunciators (FMAs) tab to a Mode Control Panel (MCP). Similarly, in AD domain, mode information is shown in different locations such as on instrument cluster [32, 53, 71, 88] or using a HUD to display it on the wind shield [33, 74, 94].

Table 2: Overview of numeric results after analysis of final publications.

	Interfaces								Methods and Techniques					Gaps			
	Verbal	Graphic	Eye caching	Multi modal	Details	Additional	Locations	Simplifying	Evaluation		Parameters	Complementary	Models/Algorithms	Insufficiency	Overload	Predicting/Monitoring	Users Preferences
									Subj.	Obj.							
AD	9	12	13	13	2	4	7	0	17	6	17	8	2	8	6	2	5
AV	3	5	8	6	1	2	2	5	13	6	13	15	12	11	5	1	2
HRI	9	2	4	4	2	0	0	0	4	5	3	4	3	4	0	3	0

4.8 Simplifying Existing Displays (AV)

In the domain of AV, there are several applications for improving and simplifying the existing System Interactive Synoptic (SIS) displays [16, 29, 55, 79, 92] to give a general overview of the current situation in an efficient way. Also to reduce the distraction and time spent, the checklists and pages for failure are simplified in several studies [29, 92].

5 METHODS AND TECHNIQUES

In this section we will outline with which methods and techniques mode awareness is addressed, evaluated or fostered in the respective domains. We specify which methods have been utilised and what parameters were taken to assess mode awareness. Additionally, we list complementary dimensions such as workload and trust, as well as models and algorithms that were used to research mode awareness.

5.1 Evaluation Methods (AD, HRI, AV)

In most of the studies in all three domains, there is a tendency to use both objective and subjective evaluation methods to asses mode awareness. For objective measurements performance data, observations and eye-tracking were utilised to assess mode awareness.

Performance data can be achieved by measuring interpreting flight data in the aviation domain cite [30, 40, 55, 92] or by simply measuring amount and time of pilot control inputs [55, 92].

In all the domains, video and audio recordings [13, 30, 55, 92] including image analysis [10], as well as researcher observations [30, 46, 55, 92] are a common way to observe user behaviour with respect to mode awareness. Such observations allow to assess users behaviour and reactions when modes change. Especially in aviation verbal call outs by pilots are used to asses changes in situation awareness [40] because the pilots often communicate about flying procedures with their co-pilots or via radio.

We found that many studies uses eye-tracking in AD [32, 53, 54, 84, 87, 94], AVI [16, 20, 21, 29, 30, 45, 55, 60, 61, 76] and HRI [6, 19, 64, 91]. It is used as tool to measure objective gaze behaviour of drivers, pilots and user interacting with robots. Eye-tracking is used on the one hand to be able to determine is looking at a mode awareness interface or to measure other factors such as stress.

Qualitative data is gained through questionnaires and interviews. In AD, AVI and HRI questionnaires [8, 14, 17, 23, 27, 29, 30, 36, 44, 45, 52–55, 73, 87, 92, 94] and post test interviews (mostly semi structured) [17, 29, 32, 44, 49, 55, 61, 69, 71, 85, 88, 89, 92] are utilized. It is remarkable that we only found one long term naturalistic study with respect to mode awareness, which was a six months study for Tesla drivers [26].

For the aviation domain the Situation Awareness Rating Technique (SART) [78] is often used [30, 31, 55, 69]. SART is a questionnaire that consists of ten dimensions to be rated on a seven point rating scale. It includes the three domains attentional demand, attentional supply and understanding. In the other domains often self construed questionnaire on situation awareness are used [91]. In the AV domain the SAGAT questionnaires for situation awareness was used [73].

If we look at the environment in which most mode awareness studies took place we can identify a clear tendency towards simulator studies. Except from a few driving test studies which are only in the AD domain [14, 26, 54, 86, 88], most of the studies in all three domains were conducted in either in a simulator or lab environment [1, 8, 16, 17, 29–33, 45, 51, 58, 60–62, 64, 69, 84, 87, 92, 94].

Simulation is done not only done with respect to the environment (flying and driving simulators) but also with respect to the mode awareness interfaces. For example, in aviation dual-task piloting simulation [51] and simulation of the flight panel [47] are applied. In HRI Calhoun et al. [10] present a multi-UAV control simulation environment on two LCD monitors. Mercado et al. use a desktop simulator system [64].

5.2 Mode Awareness Parameters (AD, HRI, AV)

As described above mode awareness is assessed objectively by performance data as well as subjectively by means of questionnaires. On a conceptual level approaches are used that assess the mode awareness interface itself or more generally by performing human-in-the-loop studies. In AVI several pilot-in-the-loop studies have been presented [16, 23, 30, 55, 79]. In AD many driver in the loop experiments have been conducted [2, 27, 35, 36, 44, 49, 52, 53, 73].

To validate the competence of certain interface applications, some user studies in AD include comparison of different levels of details or visuals [3, 27, 54, 86]. These techniques often followed by interviews or questionnaires to validate which HMI solution works best for the drivers.

Performance data include completion time [10] and actions on the interface [6]. Especially, in AD take-over times in automation level 3 are used as an measurement for mode awareness [87]. Additionally, driving performance [89] and the performance of non-driving-related tasks NDRT [87, 89] are used to determine mode awareness.

When visual attention is evaluated the parameters fixation duration [16, 19, 20, 45, 54, 55, 59, 61, 84], fixation counts [59, 61, 91], as well as saccades [59, 94] and gaze switching [19] are reported in all three domains.

Mode awareness interfaces are evaluated with respect to their usability [55]. Usability is often evaluated by means of the System Usability Scale (SUS) in AD [36, 74, 84] and AVI [29–31, 69].

5.3 Complementary Dimensions (AD, HRI, AV)

Apart from assessing mode awareness in a direct way many studies assess complementary dimensions relevant for mode awareness. These dimensions include (mental) workload, distraction, risk awareness, trust and user acceptance.

The drivers/pilots/users workload is either evaluated subjectively by means of questionnaires [8, 55] or derived objectively from physiological parameters. These are again gained from eye-tracking data [59, 92] such as pupil dilation in AD [87, 94], AVI [16, 45, 59–61] and HRI [91] or heart-rate measurement (reflecting stress level) for automation surprise [19]. For subjective workload assessment most of the time the NASA Task Load Index (TLX) is used in AD [74, 86–88], AVI [8, 29–31, 45, 55, 59, 69], and HRI [22, 91]. An alternative in AD is the DALI questionnaire for workload [84].

Other approaches measure distraction potentials of in-vehicle displays [54], risk awareness ratings in aviation [8], and the users trust in the mode awareness interface [10]. User acceptance is assed along with usability [55], utilizing user acceptance models such as the technology acceptance model (TAM) [89].

5.4 Models and Algorithms (AD, HRI, AV)

Other approaches to decrease mode confusion and foster mode awareness have been proposed by applying detection algorithms and prediction models. Especially in aviation such approaches can be identified. Prediction methods were used for the design of information systems including mode awareness. A multiple hypothesis prediction method was part of a novel flight deck information management framework which integrates all the on-board information for improving state awareness [18, 24, 25]. Young et al. [92] provide predictions of problems where mode change are highly likely to occur.

Other approaches use modeling for the detection of mode confusion such as GOMSL [51]. Lee et al, [57] have proposed a new framework based on intent inference to detect flight-deck human-automation mode confusion. Dehais et al. [20] have proposed a dispersion-velocity based detection algorithm based on blink, saccade and fixation behaviour of pilots. Heymann and Degani [43] have used formal methodology and an algorithmic procedure for constructing user-models and interfaces. Several approaches have been proposed as verification frameworks to detect a wide range of mode-confusion problems [6, 70, 81]. In HRI qualitative spatial beliefs models are applied to bridge the gap between human's mental representation about space and that of mobile robots [48].

In order to decrease negative effects of mode confusion through misbehaviour of pilots Ackerman et al.(79) [1] have presented the Flight Envelope Protection System that prevents pilots from interacting with the airplane in a way to exceed its structural and aerodynamic operating limits.

Other approaches support the pilot to deal with workload and complexity. Johnson et al. [50] propose that dynamic task allocations could help to reduce the workload of operators and help awareness. Etherington et al.(141) [31] use Predictive alerting of energy (PAE) methods (ie. predictions of the aircraft state) to provide the crew with complex information. In HRI approaches such as mixed-initiative HRI [12, 22] have been proposed. Here tasks and authority of both human and artificial agents are dynamically defined according to their current abilities. Lakhmani et al. [56] warns that such approaches are particularly susceptible to mode confusion. Also in AV formal analysis methods are used to test whether interfaces cause mode confusion or not [58].

There are also general design proposals for information presentation with a focus on mode awareness. Eriksson et al. [28] have proposed such principles based on linguistic theories such as the Gricean Maxim (cf. [39]).

In AD these approaches have been less in the focus of research. Lee and Ahn [58] have created a user interface in the ACC system based on formal methods and Baltzer et al. worked on creating interaction patterns to support the interface applications [3].

6 GAPS

The gaps contained in the papers mainly centered around general ineffectiveness of existing mode awareness interfaces due to being too simple or not nuanced enough, visual overload potentials of more sophisticated interfaces, a strong focus on visual approaches only, as well as a need for more detailed modelling, prediction, and monitoring for calibrating perceived and actual automation modes. Additional topics concerned a need for user training and mode perception differences based on cultural differences or different user profiles. HRI yielded far less results than both AD and AV, which were more substantial in terms of gaps highlighted.

6.1 Insufficiency of existing solutions (AD, HRI, AV)

Many works identified existing solutions as flawed or insufficient to adequately represent the full relevant spectrum of automation modes. In aviation, reasons given were cluttered interfaces [20, 55, 61] lack of contextual information [34, 62, 69] or simply being too simple to cover all possible interaction scenarios between human and automated system [80]. Moiser et al. further highlighted a mismatch between the "cognitive requirements of the electronic cockpit and the cognitive strategies afforded by current systems and displays" [68], further arguing that in addition to mere cues, relevant information and data needs to be provided as well, so that pilots can verify and compare the system's with their own assessments.

Horn et al. highlight that despite the increase of different operation modes to 20 in modern aviation, mode communication has hardly changed from its basic concept of simple tasks (e.g., holding altitude or heading) [45]. While many functions in modern cockpits are now automated, this is stated to lower only the manual workload, while increasing cognitive load, with mode awareness indicators needing to support an aircraft's increased automation capabilities [15], with increasing automation not guaranteeing fewer human errors, if mode awareness is not given [62]. Sebok and Wickens state that "the typical feedback is a three- or four-letter code, from which pilots should remember flight performance implications. This code is a poor display for supporting SA," [77] suggesting that flight path indicators and similar are necessary for proper mode awareness in modern aviation.

In HRI, a lack of usability for robot controls was noted [85], with a contributing issue being that of transparency and determining which information to communicate [56]. Another issue raised was a focus on additional warning signals in system design when previous alarms were ignored by the user, when an explanatory approach could be more effective for resolving automation and authority conflicts [19]. A lack of focus on information-sharing approaches between humans and system agents was also identified as a potential obstacle that inhibits proper interaction with an automated system and properly understanding and addressing its system state [82].

In AD, there is a focus on interfaces for take-over requests (TOR) [87], with the need for effectively communicating automation modes stated to have to go beyond just TORs [26] or binary (on vs. off) indicators [66]. Similar to AV, more detailed automation interfaces can be difficult to comprehend, with fewer automation modes being one suggestion to increase usability [84]. Elementary design aspects, such as colors of automation symbols [33] or size and color contrast [88] being in need of further exploration and homogenization in AD. A further issue was stated to be a lack of understanding of the technical level and resulting difficulties of properly understanding system indicators and warnings [35]. Mode awareness was also found to be dependent on the non-driving task performed by the driver during automated driving [33]. Another issue specific to AD was a reported lack of automation-specific laws and ethical considerations [5], which could, among other aspects, also regulate the information contents of mode awareness interfaces.

6.2 Visual overload and additional modalities (AD, AV)

One often stated aspect in relation to the inadequacy of existing designs and the difficulty of designing effective mode awareness interfaces was that of visual overload, with cognitive overload being a result of the former. Increasing the salience of cues in case of state or mode changes can have adverse effects [68] and in the multi-screen default setup of most aviation interfaces, any additional cue or indicator, regardless of modality, can cause confusion or overload [15]. A similar issue of balancing between effectiveness and annoyance is true for AD as well [90].

Exploring different modalities for communicating automation modes to lighten workload is often suggested across both AV and AD and seen as a gap in research and development [9, 11], although such approaches, where they exist, are not without issues as well: Auditory messages are less effective in noisy environments, such as a cockpit [20] and were reported to be rejected in general by pilots as a primary means of output [45]; haptic feedback – while effective – can quickly become frustrating or annoying due to being imprecise [8], although was noted to have potential for AD due to being perceptible without taking away the driver's visual focus [13]. Haptic feedback via the steering wheel, however, was found to have a negative impact on drivers' response [49]. A combination of audio cue and visual symbol in the instrument cluster was not found to be sufficient to communicate automation modes efficiently in AD [88]. In general, further exploration of alternative modes and multi-modal displays is called to be required [11].

6.3 Prediction and monitoring (AD, HRI, AV)

Across all three domains, situation as well as user behavior prediction and monitoring was highlighted as a mitigating strategy, which could lessen the need for mode communication via dedicated interfaces. Such approaches are stated to require formal performance models, which do not yet exist or to a sufficient degree of detail [7]. They also require development of automated tools to analyze the context and identify problems in operation, together with suitable (= high usability) interfaces [4]. In HRI, dynamic authority sharing, where conflict detection modifies the level of automation and authority of the robot, is seen as a potential strategy but is not yet sufficiently mature [19]. Approaches such as mixed-initiative HRI [12, 22], which allocates tasks and authority between the human and the robot dynamically according to their abilities are wide spread, but also are especially susceptible to mode confusion [56]. "Cognitive countermeasures", to explain the automation status to the user based on monitoring and conflict detection could be shown to have potential but such approaches are in need of further refinement [19]. Similarly, in AD lacking system transparency based on visible system and environment monitoring was identified as an inhibiting factor for effective mode awareness communication in automated vehicles [42].

6.4 User preferences, training, and cross-cultural design (AD, AV)

Individual as well as cultural factors were identified as potentially influencing the effectiveness of mode awareness cues in both AD and AV. Individual user preferences regarding feedback modes is also assumed to hold true for mode awareness-specific feedback [74]. In AD, different driving styles can lead to differences in response to the vehicle's driving behavior as well as a different understanding of its automation capabilities [42]. A lack of automation-specific driver training was further highlighted as a factor that increases the gap between a vehicles' automation capabilities and a driver's handling and understanding of said automation [2, 26].

On the cultural level, individual design aspects such as color choice were identified to bear the potential of different cultural implications [59], cross-cultural design of such interfaces more challenging. Beyond the superficial visual level, a difference in mental models across cultures can also have a strong influence on the effectiveness of an interface [41]. Both ethical and individual factors governing one's perception of responsibility were called to be in need of deeper investigation in general [71].

7 DISCUSSION

In the following, we discuss some of the more salient aspects identified and their implications regarding mode awareness in automation.

7.1 Simple vs. complex, mono- vs. multimodal

A common thread across all domains was existing interfaces often being considered too simplistic to appropriately represent a system's full automation spectrum. While the common approach to provide mode awareness was showing current mode information using verbal and graphical indicators on displays, there was also no consistent terminology across the domains on how to state it and its level of capabilities.

Compared to the other domains, we saw that AD is more open to try and develop different types of HMIs and use of multi modalities of feedback which could aims at improving the driver's experience. The least flexible domain to make changes to improve mode awareness was AV, as already was stated that might be due to the certain hesitations, limitations and strict constrains inside the aircraft. So, the tendency towards improving the mode awareness is to make simple changes such as moving the information screen to other displays, or adding extra graphics and boxes to the existing screens. In the field of HRI, where there is a close collaboration, solutions were often limited to use of buttons or color of "on" and "off" without giving enough attention or detail.

Overall, existing indicators were often a result of having been initially conceptualised for simpler automation modes and then not being expanded as the systems matured. At the same time, these indicators exist in complex control environments, where a multitude of interaction devices and indicators are already present. Thus, there is also justified hesitation to introduce additional complexity, as that could easily cause cognitive overload and decreased awareness as a result. This concerns modality as well: while focus on visual indicators was often stated as a negative, works that did focus on exploring different modalities often found them to be either poorly received or to contribute to overload instead.

7.2 Prediction - no awareness necessary?

There were several approaches that addresses mode awareness indirectly via prediction. Prediction can have three dimensions in this regard: (1) prediction of the system state, (2) prediction of the user behavior, (3) prediction of the environment. The general idea here is, that the better situations can be predicted, the less important explicit indicators are, as automation confusion and authority conflicts can be predicted and potentially resolved before they appear.

Predicting the system state (1) appears to be the most feasible strategy, although it alone can not be expected to detect or predict conflicts with users. (2) can provide just that but requires adequate user monitoring for verification, increasing the complexity significantly. (3) is a combination of (1) and (2), with (2) being extended to include all relevant agents or influencing factors. While boasting the highest predictive strength, it requires the largest number of formal modelling and is highly context-dependent. In addition, prediction is more suitable, the better controllable and/or limited the context is. Predicting a single user-system interaction in a factory environment with a small degree of external influences and little to no other human agents (e.g., in a storage hall) is more feasible than prediction of human-vehicle interaction in mixed traffic.

Thus, it is unlikely that prediction can be the sole strategy and replace appropriate mode indicators completely. It does, however, suggest itself as a mitigating strategy, which could also address the problem of simplicity vs. complexity of indicators: While it might not eliminate conflicts completely, effective prediction could reduce them to such a degree that complex mode information is no longer necessary to resolve the remaining smaller pool of possible conflicts. A combinatory approach of predictive strategies and mode indication for residual conflicts can has also an additional benefit: Since neither the prediction nor the indication needs to be able to address all situations, both can be kept to a lower level of sophistication, increasing feasibility for both and reducing the potential of overload for the indicators. Thus, a promising future direction is to consider mode awareness of nut just an issue of user warnings but a calibration of environment prediction and additional indications where necessary.

7.3 A need for more tools and long-term naturalistic studies

The literature analysis has shown that there is currently no direct way to measure somebody's awareness of the current automation mode. Methods can be divided mainly into four areas: (1) Subjective post-hoc questionnaires either targeted at situation awareness in general (e.g. SART or SAGAT) or at complementary dimensions that have an influence on mode awareness such as mental workload (e.g. NASA-TLX, DALI); (2) Observations on the reactions of users on changing automation modes. This can be achieved either by direct observation of user behaviour, or by measuring the performance after the mode has changed. (3) Utilising methods that asses whether a user has looked at mode awareness interfaces in most cases achieved with eye-tracking parameters such as fixations. (4) Usability evaluations of mode awareness interfaces often achieved my using questionnaires such as SUS.

With respect to (1) we argue for the development of new tools and questionnaires targeted at mode awareness itself and not using existing ones targeted at situation awareness in general. Especially with the advent of more nuanced modes e.g. in the AD domain and the sophisticated allocations of functions and authority there is a need for a more nuanced subjective assessment, that not only include the awareness of a specific mode, but also whether the users exactly know and understand what a certain mode means for them in terms of possibilities and responsibilities.

For area (2) we suggest that there is a need for more naturalistic long-term studies. In aviation expert pilots are trained, have long-lasting experiences and a co-pilot as a backup. With the advent of consumer AD vehicles we need to gain understanding in real driving situations, whether drivers are aware of the vehicles mode in any situation and also know how to react to mode changes. There is a clear lack of such studies.

It seems to be that especially eye-tracking studies (area 3) at least can provide insights on mode awareness interfaces and if they can attract users gazes with their design. A flaw is, that we might then know if a user has looked at a mode indicating interfaces, but we know only little whether the same user is consciously aware of the current automation mode, let alone what it means. This can be only achieved by mixed-methods approaches; e.g. by observing the users behaviour after the mode awareness interface has been looked.

For area 4 we were surprised that rather generic tools such as SUS has been used to assess the usability of mode awareness interfaces. Again we suggest that new tools needs to be developed that evaluate not only the usability, but also other factors such as trust and workload. Especially, long-term usability shall be addressed much more in our view.

8 LIMITATIONS

This literature review was conducted via several major online repositories but it is possible that relevant publications were not included due to not being indexed in either of them. Only international publications written in English were considered for this review, which could exclude relevant local advances that had not yet been disseminated to the international level at the time of writing. The screening identified a strong overlap between HRI and aviation and there was a generally lower amount of papers from HRI in the final analysis, which was surprising. While we could not find any indicators for it, it is possible that the initial search terminology was flawed for HRI specifically and that other key terms or a search farther back than 2011 would have been needed to find a larger pool of non-Aviation related HRI-literature. Finally, we only included academic literature and no manuals, system specifications sheets, demos, news articles, or similar for existing production or prototype systems. As a result, this review only covers the publicly accessible academic spectrum. The industrial state-of-the art, especially in regards to closed or proprietary sources, might feature a wider or more advanced spectrum of mode indication than is reported here.

9 CONCLUSION

In this paper, we presented the results from a literature review on mode awareness approaches across Automated Driving, HRI, and Aviation. Effective mode indication in highly automated contexts with human involvement is an ongoing challenge, which is why we looked at these three domains, where interaction with highly automated systems is of high relevance and importance. We identified existing interfaces and techniques for effective mode indication, as well as shortcomings and future potentials regarding mode awareness for all three domains.

We found that existing interfaces are often too simple to represent the full automation spectrum, yet are also difficult to expand further, due to the danger of overload with increasing complexity. Prediction was identified as a possible mitigating strategy, which could extend the range of preventable and resolvable conflicts, while keeping mode indication complexity low. Another obstacle towards better mode awareness in automation is the absence of more powerful tools and a lack of long-term naturalistic studies (i.e., in real environments) in mode awareness assessment. So it is not just the interfaces but also the methodology, which has not quite kept up with the advancement of automation capabilities.

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