A Theoretical Framework for Occupant Comfort in Future Shared Autonomous Vehicles

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Abstract. People want to be comfortable, and perception of what makes each user comfortable can vary greatly. This makes it important that vehicle products meet the different expectations of users through flexibility in their interior environment design. One of the most prominent predictions in personal mobility progression is a move towards shared autonomous vehicles. SUaaVE is a European project aiming at improving acceptance, trust and comfort of future shared automated vehicle users, through development of a system concept known as ALFRED. This paper presents a theoretical framework for an adaptive model, with comfort componentised into attributes. Application of the model aims to drive a response to vehicle user's individual characteristics and preferences - such that their comfort can be optimised intelligently by manipulation of vehicle features and functions as part of the ALFRED concept.

Keywords: Human Factors · Automotive · Automated vehicles · Comfort

1 Introduction

Asking a group of people what makes them comfortable is likely to yield responses that could, at very least, be varied. There may be some consensus in influencing factors, but even then it is likely there will be variety in what each perceives as best.

As technology of vehicles continues to progress into an automated and connected world, it is likely that we will see significant changes to the way vehicles are designed and used [1]. As models for use and ownership change it could well be possible that the needs of users change, with a consequential shift in what is perceived as 'just right' across a number of vehicle attributes – none more so than user comfort [1]. Equally, as technology moves forward, there is likely to be utilisation of advancement to increase the capability of how vehicles respond to influence levels of user comfort.

This move towards autonomous and connected vehicles, and integrating technological advancement is the primary focus of the SUaaVE (SUpporting acceptance of automated VEhicles) project. The aim is to ensure that vehicles are able to meet the expectations and characteristics of their users. The project includes a number of different factors, with this paper reviewing a framework for occupant environment comfort.

1.1 The SUaaVE project

SUaaVE [2] is European Union funded project under the Horizon 2020 research framework. The project seeks to close gaps between advancement of shared, connected, and autonomous vehicles and user acceptance, ethics, emotion, and comfort.

The project sets out to develop system able to control intelligent responses of vehicle systems in accordance with human emotions. This comprises of (a) evaluation of a passenger state, and (b) an adaptive interface and vehicle functionality. This is with the aim of manipulating aspects of interior environment, and vehicle dynamic behaviour. Also a key output of the project is guidelines to support public authorities, aiming to represent a breakthrough in public acceptance and ethics of use surrounding future CAVs. Development of components will follow an initial investigative stage of establishing models for each component. This is followed by multiple iterative testing stages with representative naïve users across multiple simulation platforms.

1.2 The ALFRED concept

The systems and their associated functions developed as part of the project will be integrated into a concept known as ALFRED (Automation Level Four+ Reliable Empathic Driver). Evaluation and response, considering changes and opportunities of automation and connectivity, is central to the concept. It intends to be agnostic of vehicle application, and instead define a theoretical amalgamation of technology and functions for integration into vehicles of the future. This is to be achieved through a series of models covering user acceptance, ethics, emotions, and of particular concern to this paper; comfort. These models unobtrusively evaluate the user and scenario, adapting the system so as to improve user experience of the vehicle.

2 Definition of Comfort

Within literature there is no clear consensus regarding a definition, nor is there an agreed theory regarding ‘comfort’. Shen and Vértiz [3] summarised the principal theories by which comfort is defined under two categories; comfort as a state of ease, and comfort as an absence of discomfort. The first of these is defined [4] as the ease or well-being surrounding physical, psychological, and physiological harmony between a person and their surrounding environment. A neutral state is defined by a lack of disturbance in a person’s environment, and general state with no sensation of 'heightened’ well-being, satisfaction, or perception of being at ease [5]. This is visualised in Fig. 1.

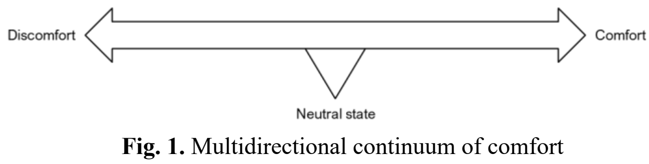

Fig. 1. Multidirectional continuum of comfort

The second explains comfort in terms of an absence of discomfort [6][7]. Under this theory a state of 'comfort' is regarded as the optimum and is subsequently a starting point of a continuum of discomfort. Here comfort is quantified by the degree to which a person identifies discomfort. This theory is shown in Fig. 2.

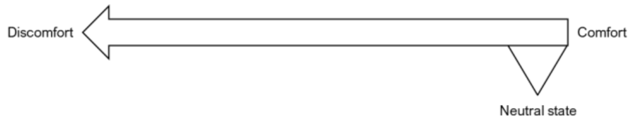

Fig. 2. Unidirectional continuum of comfort

Following on from these models, more recent definitions seek to separate the concepts of comfort and discomfort. Vink and Hellback [R] describes it being a reaction to the environment with comfort as a pleasant state or relaxed feeling and with discomfort as an unpleasant sate. These definitions both find origins in literature describing factors influencing comfort and discomfort. One of these developed as part of a model by De Looze et al. [8] separated the concepts of discomfort and comfort under distinct characteristics. Here, both are considered as influenced by human, product, and environmental characteristics. Subsequently Vink and Hellback [9] developed a model taking into account the earlier models by De Looze et al. [8] and others such as Moes [10].

Considering the basis from existing theory and research, it can be said that there is no absolute definition of comfort. That said, there is some consensus in its components. The quantification of comfort in terms of positive and negative sensation governing overall state is widely used as a reference point of various theory. Generally physical, physiological, psychological, and emotional components are considered as influences on human perception of comfort. Likewise, environment, user traits, and product attributes are seen as factors that can affect and manipulate how comfort is perceived.

2.1 Vehicle comfort

The comfort of vehicles has been widely studied throughout the history of automotive research and development, dating right back to the early 20th century [11] and continuing up until to present day. As available technology has evolved the means of enhancement to the comfort of vehicle occupants has become progressively more advanced. This is evidenced by increases in available features intended to impact perception of vehicle comfort, and development in associated capability and performance. Further to these developments, have been the implementation of sensors and the increased intelligence of adaptive systems, which have increased the possibilities regarding how a vehicle occupant's experience of comfort can be influenced [12].

Vehicle comfort closely connects with general comfort definition, with several identifiable product attributes regarding vehicle design [12][13][14][15]. User characteristics depend on the physiological, psychological, and physical state of the occupants. These are associated with personal traits (e.g. personal preferences, physical characteristics) and their momentary state (e.g. state of stress, presence of pain, tiredness). User characteristics might also take into account the context and the scenario (e.g. trip urgency occupant activity, trip purpose). Environmental factors take into account elements within which the vehicle operates (e.g. weather condition, road surface, vehicle).

3 Solutions to be investigated

3.1 Development of Ambient Comfort Model

As described, and central to the SUaaVE project, implementation of connected and autonomous vehicles has the potential to greatly change in-car comfort perception. This is in part attributable to the potential change in characteristics that the vehicle has to respect in order to optimise comfort, and also attributed to technological advancement.

Based upon the principals behind both, there are two aspects that must be developed – first an approach by which different factors influencing comfort can be assessed and measured so as to quantify the level of comfort for users. Second will be the definition of a means to manipulate elements influencing the degree of comfort for users. This will function such that vehicle systems are able to work to improve their level of comfort. This represents a key innovation on the part SUaaVE, with this 'intelligent' response based upon understanding of the user and scenario of use central to the project

Vehicle comfort can broadly be divided into two categories according to the engineering challenges posed – dynamic comfort, and interior (ambient) comfort. The influence of both is considered by the SUaaVE project and, whilst separate, dynamic comfort is set to follow a framework close to that defined in this paper. During later ALFRED concept integration there will be an assimilation of the two. Following definition, the comfort model will be evaluated by means of iterative testing across multiple phases. This is intended to be carried out within a simulated scenario and environment.

3.2 Components of Ambient Comfort

In response to evaluated theory and models within existing literature, a process of comfort definition took place as part of the SUaaVE project. A parallel framework for dynamic and ambient comfort was used, separated into a series of components representing overall comfort when comprised. At the component level this will allow for assessment of state, whilst forming the basis of combined assessment of comfort controlling the ALFRED response. Seven components were identified from a larger pool:

- **Thermal Environment** covers the thermal environment of the vehicle cabin, following the individual characteristics and state of each user.

- **Acoustic Environment** refers the vehicle cabin sound and vibration

- **Visual Environment** refers to occupant environment visible components
- **Postural position** refers to components of the occupants physical position when inside the vehicle cabin, following characteristics and state of users
- **Environmental Hygiene** is comprised of a variety of factors governing user sensations of cleanliness and hygiene whilst traveling within the vehicle.
- **Spatial Environment** defines level of perceived space within the occupant environment with relation to the demands of the user
- **Tactile Interaction** concerns perception whilst interacting tactile surfaces

3.3 ALFRED Integration

The foundation for inclusion the SUaaVE model, is the basis for comfort components to be influenceable by the generic vehicle features and functions included in the scope of control the ALFRED concept. Individual comfort components have been linked to those features which have a corresponding impact (Fig. 3.)

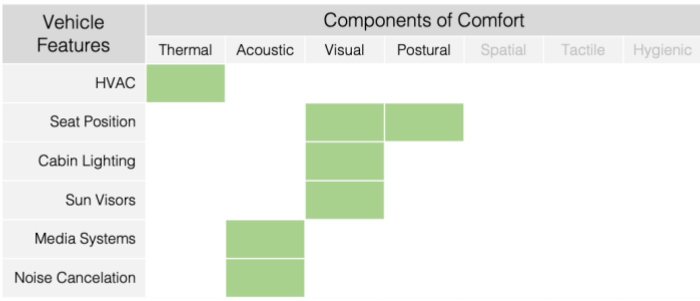

Fig. 3. Components of Comfort in ALFRED

Control of features used to manipulate the comfort of occupants will be presented through the aforementioned interface developed in conjunction with the ALFRED concept. This interface will have comfort functions driving adjustments to corresponding vehicle feature settings. The interaction strategy itself will present recommendations based upon the output of the model, requesting confirmation from the user.

3.4 Ambient Comfort Concept

It will be the role of the ALFRED concept sensor technology to determine the comfort status of occupants. The underlying assessment methodology at the components level determines this comfort state by data regarding occupant state of, their traits and preferences, situational factors, and environmental conditions. This will quantify sources of discomfort regarding the user or scenario and measure discomfort at the component level. Output will then dictate functional recommendations to the ALFRED user interface.

Referring to the aforementioned concepts, assessment is to follow a unidirectional continuum of *Figure 2*. This is measured for each data source and provides an overall output. Also included in the output is determination of the degree of discomfort for each component and its theoretical route cause. With this functionality causes behind states of discomfort can be identified and counteracted through ALFRED – improving overall sensation of comfort. This through shaping conditions controllable by the vehicle, and closer to what might be regarded as ‘just right’ for each specific user and scenario.

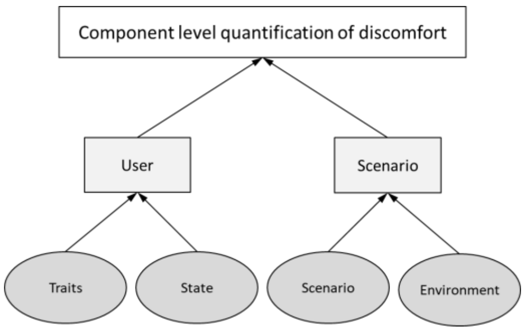

Fig. 4. Model for (dis)comfort assessment

4 Continued Development and Evaluation

An initial version of ambient comfort profiles must be built up in the next phase of the SUaaVE project. This leading phase must include investigation around each component of ambient and posture settings with relation to identified vehicle features. The aim is to identify specific feature functionality in terms of component level comfort impact. This is to be based upon existing literature and in conjunction with expert assessment – replicating individual influencing factors associated with each assessment.

The outcomes from this initial investigative phase are then planned to be tested with a sample of participants. A first stage of evaluation will follow directly from the initial phase, with separate components assessed independently. This subsequent data set will be applied to developing the ALFRED functions responding intelligently to manipulate comfort state. Subsequent testing stages will combine comfort components within progressively diverse simulation platforms and, through iterative testing phases, refine combined functions able to impact vehicle occupant comfort perception. During this phase the ALFRED ambient comfort functions will be joined with dynamic comfort modelling and assessment of emotions investigated elsewhere in the SUaaVE project.

5 Conclusion

Comfort is evidently defined under may different models and structures. There is, however, some consensus within the previous investigation and definition with theories finding their basis in the separation between states of comfort and discomfort. Regarding vehicle comfort, there is also a wide variety in approaches surrounding its investigation and development. Most apparent from comfort properties of vehicles is the continuous trajectory of development, with its scope only set to be amplified by the technology enabled as vehicles move towards autonomy and connectivity. This is also set to run in parallel with moving user expectation as models of use change.

SUaaVE sets out to develop the ALFRED concept and provide a basis for implementation of future technology, with the consideration of users at its heart. The first phases of development defining ambient comfort assessment and response in conjunction with this intelligent system are defined within this paper. Subsequent development phases objectively assess the model, with progressive stages of iterative investigation, development, and evaluation. The final aim is to present a framework assessing user comfort, with output influencing intelligent vehicle functionality.

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References

1. Diels, C., Erol, T., Kukova, M., Wasser, J., Cieslak, M., Payre, W., Miglani, A., Mansfield, N.J., Hodder, S.G. and Bos, J., Designing for comfort in shared and automated vehicles (SAV): a conceptual framework. Presented at the 1st International Comfort Congress (ICC2017), Salerno, Italy (2017)
2. SUaaVE European project, http://www.suaave.eu
3. Shen, W., Vértiz, A.M.: Redefining seat comfort. SAE transactions. 1066--1073 (1997)
4. Osbourne, D.J., Clarke, M. J.: The development of questionnaire surveys for the investigation of passenger comfort. Ergonomics. 16.6, 855--869 (1973)
5. Slater, K.: Human comfort. C.C. Thomas, Springfield, Illinois (1985)
6. Hertzberg, H.T.E.: Seat comfort. Annotated Bibliography of Applied Physical Anthropology in Human Engineering, WADC Technical report. 56--30 (1958)
7. Branton, P.: Behaviour, body mechanics and discomfort. Ergonomics. 12.2, 316--327 (1969)
8. De Looze, M.P., Kuijt-Evers, L.F., Van Dieen, J.A.A.P.: Sitting comfort and discomfort and the relationships with objective measures. Ergonomics. 46.10, 985-997 (2003)
9. Vink, P., Hallbeck, S.: Comfort and discomfort studies demonstrate the need for a new model. 271--276 (2012)
10. Moes, N.C.C.M.: Analysis of sitting discomfort, a review. Contemporary ergonomics 2005. 200--204 (2005)
11. Warner, J.A.C.: Riding-qualities research. SAE Transactions, 193--226 (1924)

12. Cieslak, M., Kanarachos, S., Blundell, M., Diels, C., Burnett, M. and Baxendale, A.: Accurate ride comfort estimation combining accelerometer measurements, anthropometric data and neural networks. Neural Computing and Applications. 1--16 (2019)
13. Elbanhawi, M., Simic, M., Jazar, R.: In the passenger seat: investigating ride comfort measures in autonomous cars. IEEE Intelligent Transportation Systems Magazine. 7.3, 4--17 (2015)
14. Zhang, E., Zhang, Q., Xiao, J., Hou, L., Guo, T.: Acoustic comfort evaluation modeling and improvement test of a forklift based on rank score comparison and multiple linear regression. Applied Acoustics. 135, 29--36 (2018)
15. Danca, P., Vartires, A. and Dogeanu, A.: An overview of current methods for thermal comfort assessment in vehicle cabin. Energy Procedia. 85 Supplement C, 162--169 (2016)