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A Holographic Infotainment System for Connected and Driverless Cars: An Exploratory Study of Gesture Based Interaction

Nicholas Lambert, Seungyeon Ryu, Mehmet Mulla, Albert Kim

***Abstract*—**In this paper, an interactive in-car interface called HoloDash is presented. It is intended to provide information and infotainment in both autonomous vehicles and 'connected cars', vehicles equipped with Internet access via cellular services. The research focuses on the development of interactive avatars for this system and its gesture-based control system. This is a case study for the development of a possible human-centred means of presenting a connected or autonomous vehicle's On-Board Diagnostics through a projected 'holographic' infotainment system. This system is termed a Holographic Human Vehicle Interface (HHIV), as it utilises a dashboard projection unit and gesture detection. The research also examines the suitability for gestures in an automotive environment, given that it might be used in both driver-controlled and driverless vehicles. Using Human Centred Design methods, questions were posed to test subjects and preferences discovered in terms of the gesture interface and the user experience for passengers within the vehicle. These affirm the benefits of this mode of visual communication for both connected and driverless cars.

***Keywords*—**Holographic interface, human-computer interaction, user-centered design, Gesture.

I. Introduction

THE arrival of autonomous vehicles offers a very different automotive experience to anything previously seen during the age of the car. Recent studies examining CAVs (Connected and Autonomous Vehicles) look at the ecosystem of "CAV technologies" that provide such vehicles with their capabilities, including computer imaging and safety critical systems, plus radar, LIDAR and GPS. The distinction between the two types is as follows:

- "Connected Vehicles (also known as Cooperative Intelligent Transport Systems (C-ITS)): [vehicles] with increasing levels of connectivity which allows them to communicate with their surrounding environment […]
- Autonomous Vehicles (AVs) (also known as automated, self-driving or driverless vehicles): Vehicles with increasing levels of automation will use information from on-board sensors [so] they can understand their global position and local environment and enable them to operate with little or no human input for some, or all, of the journey" [1].

With the increased potential for a variety of in-car information and entertainment systems aimed at the increasingly unoccupied driver of an AV, there must be consideration of several factors in their design. We propose a gesture-based holographic system mounted within the car dashboard that is responsive to the driver in full AV mode but also enables the drivers of transitional CVs to interact when not fully occupied with driving. We propose an HCI methodology to examine responses from potential users and suggest how this could be incorporated into the design of future interactive in-car systems.

N. Lambert and M. Mulla are at the Research Office, Ravensbourne, North Greenwich (e-mail: n.lambert@rave.ac.uk).
S. Ryu and A. Kim are with DoubleMe, Inc. 5FL, 629 Sampyeong-dong, Bundang-gu, Seongnam-si, Gyeonggi-do, Korea.

II. Context

Technologists and policymakers have defined five or six levels of automation in cars, ranging from 0 (no automatic control) to fully automated operation. A typical breakdown is that from the National Highway Traffic Safety Administration (NHTSA):

> "Level 0: The human driver is in complete control of all functions of the car; Level 1: One function is automated; Level 2: More than one function is automated at the same time (e.g., steering and acceleration), but the driver must remain constantly attentive; Level 3: The driving functions are sufficiently automated that the driver can safely engage in other activities; Level 4: The car can drive itself without a human driver" [2].

With the possibility that human drivers might be released from controlling their vehicles for part or all of their journey, the interior of the car can be reimagined as a space for entertainment and the display of new information. In 2015, the Ars Electronica FutureLab worked with Mercedes Benz on their F 015 concept autonomous car that featured a fully open interior with swiveling seats, allowing all passengers to turn and engage with each other. It also had a complete wrap-around set of screens running over the ceiling, dashboard and door surfaces. The promotional videos for the F 015 show it being aware of its environment, projecting images onto the road beyond it as well [3]. Although such a car is still very much at the prototype stage, it shows how all-encompassing in-vehicle information could become.

In the UX roadmap for AVs laid out by John Rousseau and Brad Crane of the Artefact Group, informed by their 2015 study with Hyundai, they identified three processes that would enable the transition. The first phase would establish both rational and emotional trust with drivers in the phase of SAV (semi-autonomous vehicles). The second phase would be that of designing the co-pilot, in terms of the autonomous car's relationship with its driver: "a hybrid mental model of shared control". Finally there would be a third phase of embracing the passenger, at the point where the car no longer needs input from a driver to work [4].

Before fully driverless cars reach consumers, Connected Vehicles will increasingly assume autonomous functions. At this stage there are significant opportunities for drivers to interact with their vehicles whilst driving but they may still be prone to being distracted as well. Such distractions can take several forms, such as the need to monitor car functions, or unexpected events like people crossing the street [5]. A report from the University of Michigan showed that drivers make brief glances at the road lasting up to 1.5 seconds' duration, but responded to visual demands of driving by making more, but shorter glances. Actions such as glancing at a map took up to 2.1 seconds [6]. Therefore, any information system that proposes to engage drivers during the transition period of CVs to AVs must recognise such risks of multitasking and as far as possible avoid encouraging more glances than is necessary.

The system currently referred to as HoloDash has been developed by DoubleMe, Inc. and is intended to operate in a fully connected environment that could either be a connected car or a fully AV. It uses a self-contained projector inside a tubular screen, the HoloTube, connected to a Leap Motion interface. Although other concepts have evolved around virtual reality in cars, such as CarVR from Ulm University in Germany, the HoloDash aims to overcome the restrictions of using a head-mounted display which would of course be prohibitive for the driver. Also, as CarVR has discovered, current generation VR headsets suffer from the relative motion of the vehicle and workarounds have to be found [7].

As car automation increases, the driver becomes more of a co-pilot than a solo controller. The question that needs to be addressed, however, is whether the driver can interact with the HoloDash interface in a safe manner. Can this be achieved whilst simultaneously responding to the world outside vehicle or would it be deemed too distracting to a driver trying to maintain control of the vehicle? After all, there are already legal requirements limiting the use of mobile phones in moving vehicles.

III. Developing the System

In this regard, the mid-air gesture interaction that underpins the HoloDash concept might be less distracting than current touch based interaction on flat screens. The interactive system should follow the heuristics set down by Jakob Nielsen over twenty years ago, such as ensuring a match between the system and the real world, in terms of speaking the user's language; and ensuring recognition rather than recall, i.e. ensuring the user does not have to remember too many actions, by making actions and options visible [8].

Nielsen's other important heuristic in this context is consistency, i.e. that there should be a specific set of simple actions needed to perform certain common tasks. This is of particular urgency given the position of the HoloDash on the side of the steering wheel (in a CV): the driver cannot make too many movements when driving and some of those might be misinterpreted.

At Ravensbourne College, a team from the Learning Technology Research Centre under Carl Smith is working on user standards for wearable technologies, as part of the Horizon2020 WEKIT project. They used the ISO 9241-210 standard 'Human-centred design for interactive systems,' which is also relevant for this project because it outlines four basic activities that need to be repeated through user testing:

- Understanding and specifying the context of use,
- Specifying the user and organizational requirements,
- Produce design solutions, and
- Evaluate designs against requirements [9]

For the HoloDash project, the context of use is the in-car environment; the user is the driver or front passenger; the design solution involves the gesture-based UI; and the evaluation process is detailed below. There was a need to investigate the following:

- Positioning of the display in the context of the dashboard
- A repertoire of gestures that would be simple enough for the driver to remember
- Demonstrative graphics and user content.

In order to trust the interface in the context of in-car interaction, the gestures need to be memorable and reliable. Certain types of imagery might be more distracting to drivers, such as complex three-dimensional graphics requiring extensive parsing. Instead the HoloDash offers an animated figure that communicates specific states of the car (fuel, temperature, water level etc) with a memorable visual image.

The information displayed would offer additional functionality, presented through the HHVI. Further enhancements to the experience could be achieved through a custom setup which could personalise the imagery to suit each user of the information entertainment system.

Compared with a traditional display, the suggested interface (Fig. 1) gives priority to the information and enables responsive interaction to the situations and surroundings of the vehicle.

In early experiments with users, we found issues with the traditional layout and methods of touch-based interaction. Most of the OBD information and of relevant vehicle/driving information is presented by texts, requiring the user's attention to read and touch the screen. This is obviously dangerous in a driving situation.

The suggested 3D display, however, prioritizes the content according to the situations the vehicle or the user is faced, layering them on the 3D space. It achieves this by organising the information vertically and bringing certain elements, like the human avatar, to prominence. This will allow the driver's eye to see the most relevant information more quickly. For example, when requiring a user's attention, the alarm signal appears bigger with an enhanced visual effects and legibility, altering its shape.

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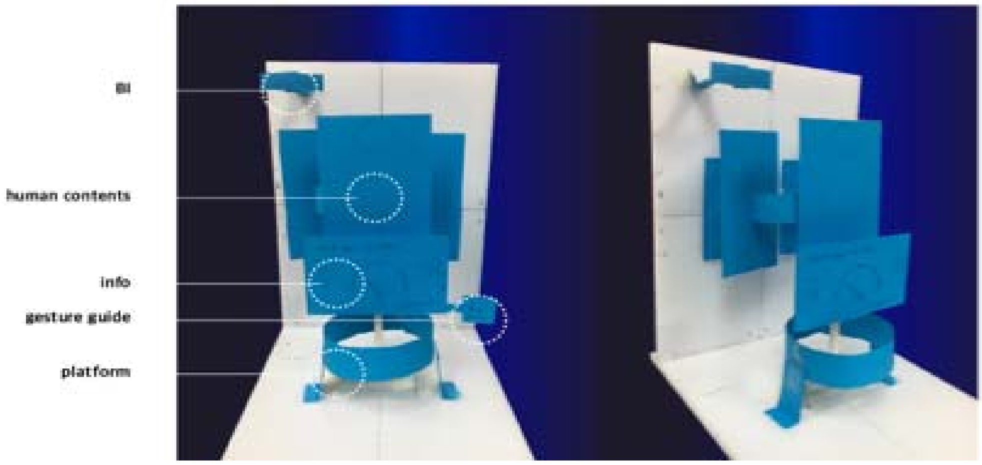

Fig. 1 Layout of relevant information in the HoloDash system

IV. Gestures

The Leap Motion was chosen as the interface controller because of its ability to recognise gestures versus other similar controllers. The Leap Motion SDK is flexible when used with Unity to control 3D models and the built-in gestures relatively simple for users to understand. The sensing of hand positions was generally good, except for certain movements that required the hand to be turned downwards. We concurred with the findings of Zhang et al who found that:

The built-in Leap Motion hand detection system presents some limitations in estimating the pose of a user's hand in the real world, but it still constitutes a workable device for rapid prototyping of real world gaming environment conditions, particularly when the controller is placed on the desk [10].

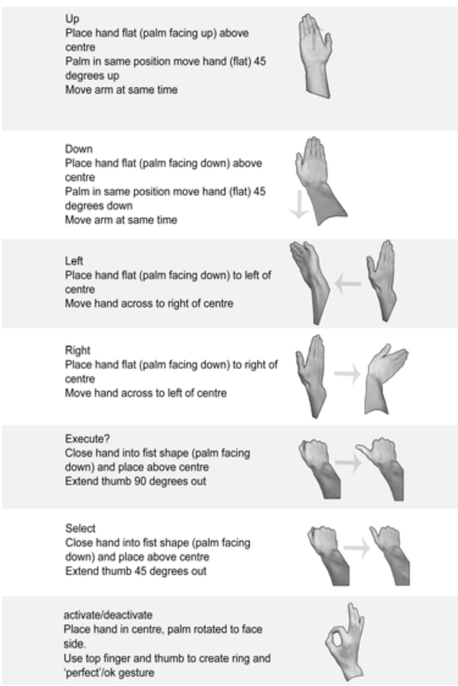

Fig. 2 Gestures used for HoloDash

Although the Leap Motion works best in close proximity to the user, this is ideal for an in-car setting, and it has an accuracy of 0.2 mm [11]. Because it tracks whole hand the Leap Motion sees the palm and the finger-joints. It also has a model of the human hand to enable it to continue functioning when parts of the hand are hidden from view [12]. Furthermore, in order not to conflict with the general movement of passengers or driver, gesture-based interactions may require exaggerated movement. For instance, moving a hand towards the car's windshield might not trigger the device, while putting the palm straight forward will be detected.

One outcome of initial research with the HoloDash is that the Leap Motion may need to learn individual users' gestures in the course of tutorials. Some users were naturally more adept than others in producing the required gestures because individual users' hands may result in subtle differences that are picked up by the IR sensor on the device. For this reason, the most useful gestures were the strong and unsubtle movements such as "left", "right" and "execute" (See chart above) [13]. In respect of this, the larger motions engaged by both the Leap Motion and the Microsoft Kinect utilise gross motor skills, but at times fine motor skills are also necessary to interact with features of the HoloDash.

The focus and responsiveness of a driver are pivotal to a safe journey. They are important factors which require the complete attention of the person at the steering wheel. While the natural gesture technologies through Leap Motion and Microsoft's Kinect usually engage gross motor skills, it is sometimes more suitable and appropriate to rely on fine motor skills to achieve goals, especially in a vehicle. [14]

Natural gesture devices can sometime prove to be quite sensitive and so mechanical interaction is preferable in some situations. It is the reason why many smart interfaces have mechanical buttons for basic but important functions. These functions should in the same light be reserved as a safeguard in the event of a failure, i.e. the obvious on/off options.

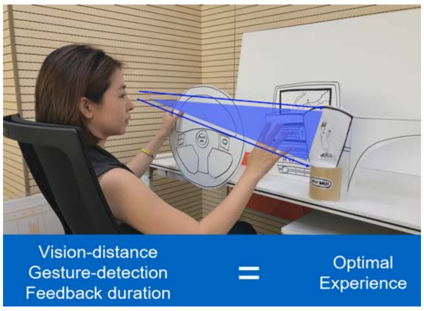

Fig. 3 Mock up of the HoloDash system

Fig. 4 Mock up of the HoloDash system

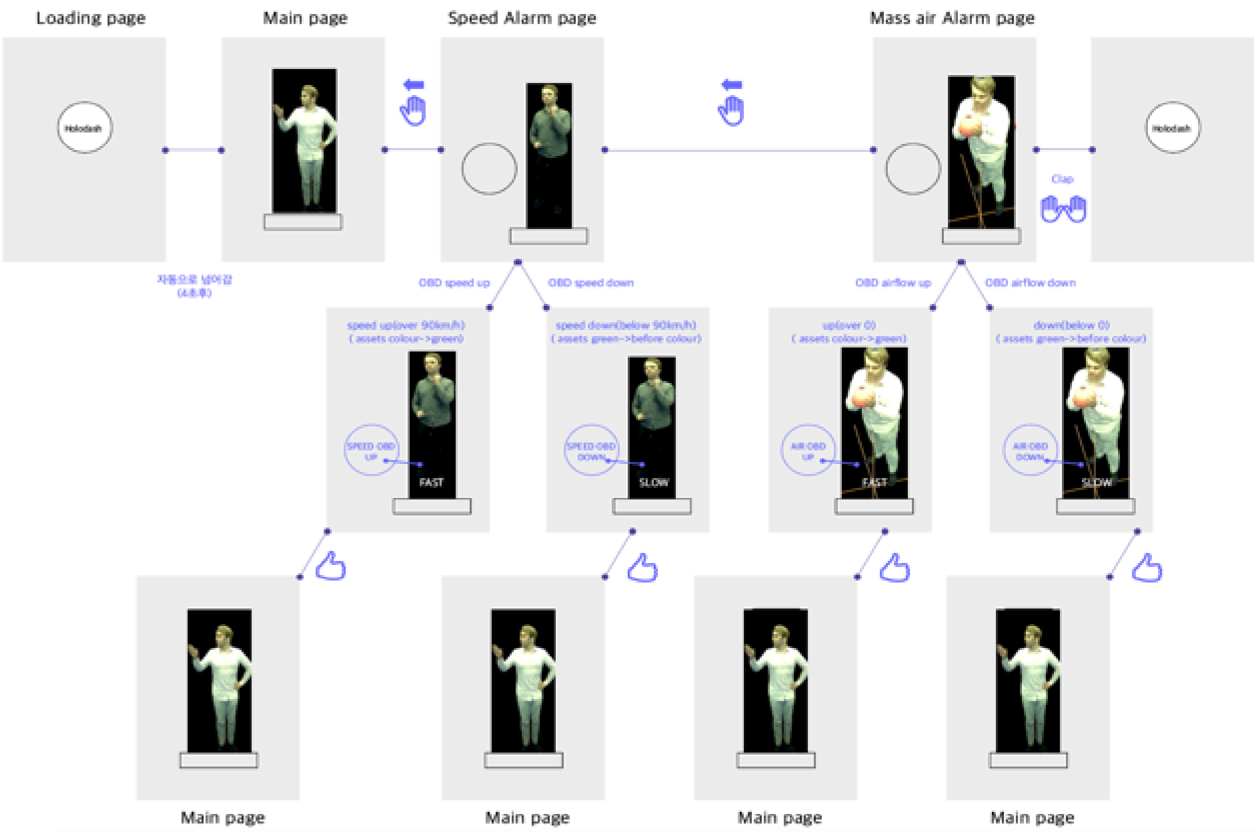

Fig. 5 Holographic avatars showing different notifications in the system

Fig. 6 Proposed HHVI content, created by DoubleMe's holoportal for use in the Holodash system

The system could also use audio to mark successful gesture responses. It is important for users to get strong confirmation is important although responsiveness can be represented through haptic feedback as well. At present this system does not have a haptic component. Pressing a button symbolises the execution of an action, so on a display this action is represented through the state change of the digital graphic: in this case the inner fill of graphic changes colour and this is also supported through the use of sound. With this in mind, an intuitive reliance on notification systems is obvious and so this aspect would not be affected by the use of a holographic distribution of information however the context of these notifications would play an important part. Even so, the driver should spend as little time as possible looking at the system if they are at the controls of the vehicle whilst it is moving.

V. Testing

To enable testing of the concept, a range of user-based observation, focus groups and surveys were created. These were used in conjunction with a prototype to help better understand how the end user would interact in a CV or AV vehicle environment.

We followed as far as possible the requirements of the HCD process and fed initial user input back into later iterations of the design. Our discussion sessions and questions were intended answer the following questions:

- Gesture interaction possibility: which gestures were preferred?
- Overall UX and service: how did users respond to the general concept of the HoloDash?
- Preference of Interaction types
- Possible Contents displayed on the HoloDash / HoloTube system

At this stage an actual car dashboard was not utilised, although several manufacturers are examining the project to utilise in upcoming vehicles. A model dashboard and steering wheel was created, with the HoloTube located in the centre and its associated equipment recessed alongside it. Only the Leap Motion was exposed in order for it to function.

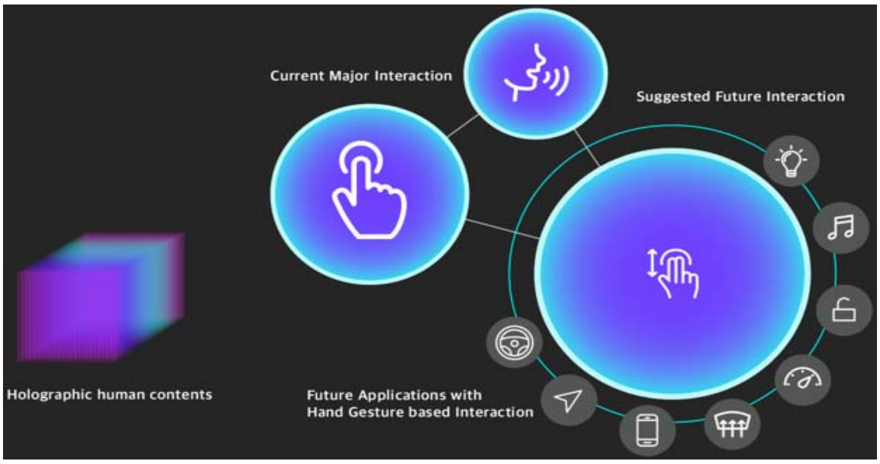

Fig. 7 Experimental interface for hand gesture interaction

A group of 25 students aged between 18 and 26 from Ravensbourne were extensively interviewed in the week of 6th December 2017 to assess their responses to the following questions:

Study One: Assessing the gestures

Question 1: how suitable is the "Up" gesture?

	1 STAR	2 STARS	3 STARS	4 STARS	5 STARS	TOTAL RESPONDENTS
Comfort	7.69% 2	15.38% 4	26.92% 7	26.92% 7	26.92% 7	26
Ease of Use	0.00% 0	26.92% 7	34.62% 9	26.92% 7	15.38% 4	26
Accuracy	0.00% 0	30.77% 8	46.15% 12	19.23% 5	7.69% 2	26
Memorable	0.00% 0	11.54% 3	30.77% 8	26.92% 7	30.77% 8	26

Fig. 8 Responses for hand gesture interaction

The other gestures – 2. Down 3. Left 4. Right 5. Start 6. Select 7. Enable-Disable – were also rated for Comfort, Ease of Use, Accuracy, and Memorability.

Study Two:

This examined the qualitative aspects of hand gestures being used in a vehicle environment. The study began with a question about the methods of interaction that the students currently use in cars with other electronic devices.

Q1: In order of preference (1 being the highest), Which method do you use to interact with a car's entertainment system?

	1	2	3	4	N/A	TOTAL	SCORE
Speech	30.43% 7	30.43% 7	17.39% 4	8.70% 2	13.04% 3	23	2.95
Touch-screen	45.45% 10	27.27% 6	18.18% 4	0.00% 0	9.09% 2	22	3.30
Gesture	13.04% 3	26.09% 6	34.78% 8	17.39% 4	8.70% 2	23	2.38
Other	9.52% 2	4.76% 1	19.05% 4	42.86% 9	23.81% 5	21	1.75

Fig. 9 Responses for entertainment system

Q2: Do you think the use of hand gestures could become common in future interactions with digital interfaces? – There was a unanimous answer Yes to this question.

Q3: Would [using gestures] interfere with your communication expressions i.e. expressive hand gestures while talking or using the vehicle?

Q4: In a vehicle environment which features do you use? Order most to least? (1 being the highest)

Music, Phone and Navigation were the most popular

Q5: How do you interact with them? Touch

Q6: Do you feel using hand gestures to operate a system could be better than Speech and touch? - Yes

Q7: Could hand gestures be the future of motoring, especially within driverless cars? Yes (56%)

Q8: When driving, In what situation would hand gestures be less convenient? (You can choose more than one)

Steering wheel operation (66.7%) Expressive hand movement while talking (50%) Having passengers operate the controls unwittingly by gesturing (50%)

Q9: In what way could these gestures be used efficiently?

- They need to be as similar to a manual gearbox as possible in terms of position and movement
- Quick changes of options quicker changes of gears and navigation and direction
- When driving on straight roads that require less hand activity
- Music or weather reports for example

Q10: Could you see yourself interacting with a holographic interface/avatar as part of the experience?

Yes (66.7%)

In general, the results show that the majority of those tested are open to using gesture-based interaction within a vehicle environment. Many found the gestures within the demonstration and those presented through discussion, to be agreeable. Those presented through discussion while not programmed for use through the 'Leap Motion' device, were recognisable by it and could be distinguished between in non-user tests. A survey relating to these particular gestures, asked users to rate each of the seven gestures in terms of comfort, ease of use, accuracy and memorability.

ANSWER CHOICES	RESPONSES	
Yes	62.50%	15
No	16.67%	4
Not sure	20.83%	5
TOTAL		24

Fig. 10 Responses for hand gestures

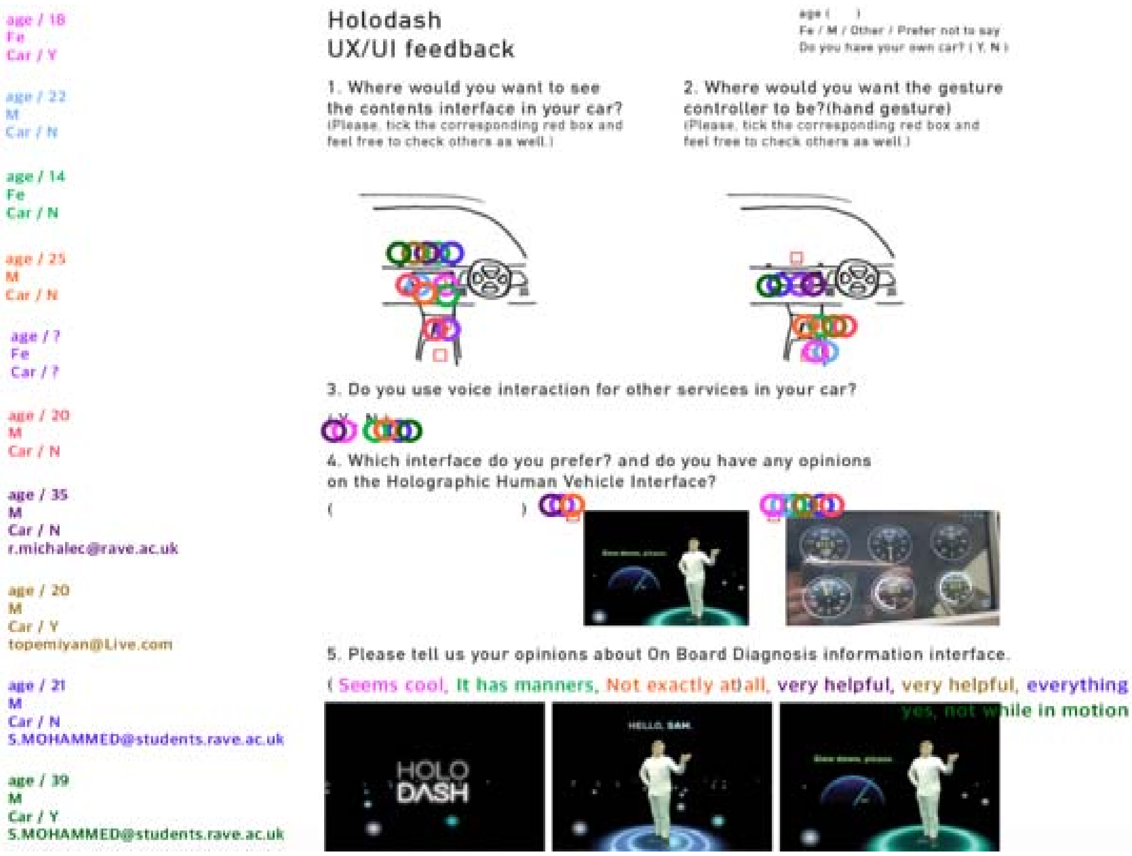

Fig. 11 Results from survey page

During a further survey of 22 students, it was found that potential users are positive about gesture in the car, but they still have to figure out how/where it can best be deployed. Their preference is to control simple car functions through gesture. However potential users are positive about the use of human avatars to display in-car statistics

Detailed Results

1. Potential users prefer navigation & middle- window position for placing contents.
2. Potential users prefer navigation/ gear handle part for hand gesture controller.
3. Some people use voice interaction for managing other

functions in the car.

4. Still many users (about 65%) prefer previous OBD info interface, but also there are some positive opinions about HHVI.
5. About OBD info interface, about 75% potential users have interests about the UI.

In terms of the main testing, results showed that while users were open to the use of this form of interaction, they felt it would be less suitable for use in the front of the vehicle be it the driver or the driver side passenger.

It was confirmed through discussion that the system should perhaps only provide visual moving interface when the vehicle is not moving, much like the process of a vehicle with a convertible roof which cannot change states while moving. The results of this query averaged at 45% meaning many would still prefer to operate a system via current means, where they believed speech and traditional touch would be more suitable

The functionality associated with vehicle user interaction suggested that use of music players and navigation were the highest in terms of use within a vehicle environment, followed by communication. It was suggested through user input that the gestures and system could be used to change music track and volume.

They believed the use of air gesturing would be put to best use through use of these. This scenario would no doubt provide a good testing ground for air gesture interaction as well as a HHVI.

In discussion they raised concerns about use of the above but also stated that they would have no problem with its use in a completely driverless car, with results also showing that control of other aspects of the vehicle as well as the aforementioned would be welcome to.

While many would welcome the system, they would find its use more feasible if integrated into the vehicle's steering wheel, as has become common practice in the interior design of vehicles in the last few years. This however should not be confused with gesturing over the steering wheel itself as opposed to mechanical triggers which this scenario describes.

The use of voice activated controls was also discussed in the focus groups and whether it should be a treated as a substitute to the use of air gesturing in terms of suitability in a car environment or a substitute to the to safety considerations.

While the Leap motion does offer a decent tracking system for air gestures, the amount of different gestures required within the vehicle environment as well as the range of movement needed when driving the vehicle, would be more problematic than beneficial. To ensure the correct gesture is made would require the user's hand to be at a specific position in terms of x y and z space and a deliberate movement of the wrist and hand for each of the steps required to make the gestures. This is not impossible but would require effort and focus, neither of which can be afforded when the driver's focus is on controlling the vehicle as it moves.

In a driverless environment in am AV this would not be a problem and the space for movement would be less of a concern for the passenger and would allow more than one to interact with the system. It seems in both cases the most suitable outcome of using a HHVI would be to allow voice control to be the primary means of interaction rather than air gestures.

Fig. 12 Experiments for the positioning of the display and input system and the UI/UX

VI. Conclusion

AVs are already working in the streets of some major cities and connected vehicles are widely used across the world. With the growth of these new modes of transportation, there is a need for novel interfaces to provide new modes of in-vehicle communication.

In the HoloDash, the potential for this emerging type of communication with in-vehicle avatars is now being established. As our user testing indicates, although there is some reservation about the usage of this system in a car with a driver, it offers a useful interface with systems in both CAVs. The system will continue its development with DoubleMe and further tests will be made with several major automobile manufacturers in the course of this year.

References

[1] Market Forecast for Connected and Autonomous Vehicles (7th September 2017): Centre for Connected and Autonomous Vehicles; https://www.gov.uk/government/publications/connected-and-autonomous-vehicles-market-forcecast accessed 22nd December 2017.

[2] J. M. Anderson, N. Kalra, K. D. Stanley, P. Sorensen, C. Samaras, O. A. Oluwatola, *Autonomous Vehicle Technology: A Guide for Policymakers* (RAND Corporation, Santa Monica Calif. 2016), pviii.

[3] "F 015: Luxury in Motion", Ars Electronica 2015, https://www.aec.at/postcity/en/f-015-luxury-in-motion/ .Accessed 22nd Dec 2017.

[4] J. Rousseau and B. Crane, "The Human Transition To Autonomous Vehicles", The Artefact Group, October 27th 2015, accessed Friday 22nd December - https://www.artefactgroup.com/articles/the-human-transition-to-autonomous-vehicles/ Accessed 22nd Dec 2017.

[5] C. P. Janssen and L. Kenemans, "Multitasking in Autonomous Vehicles: Ready to Go?"; proceedings of *AutomotiveUI'15* September 1-3, 2015, Nottingham, UK ACM 978-1-4503-3736-6, p3.

[6] O. Tsimhoni , H. Yoo, P. Green, "Effects of Visual Demand and In-Vehicle Task Complexity on Driving and Task Performance as Assessed by Visual Occlusion", Technical Report UMTRI-99-37 December, 1999, http://www.umich.edu/~driving/publications/UMTRI-99-37.pdf, accessed December 22nd 2017.

[7] P. Hock et al, "CarVR: Enabling In-Car Virtual Reality Entertainment": CHI 2017, May 06 - 11, 2017, Denver, CO, USA.

[8] J. Nielsen "10 Usability Heuristics for User Interface Design", January 1, 1995 https://www.nngroup.com/articles/ten-usability-heuristics/, accessed 16th Dec 2017.
[9] C. Smith et al, D5.3 WEKIT Workplace Integration, Wearable Experience for Knowledge Intensive Training, http://wekit.eu/wp-content/uploads/2017/08/WEKIT_D5.3.pdf.
[10] Y. Zhang, O. Meruvia-Pastor (2017) Operating Virtual Panels with Hand Gestures in Immersive VR Games. In: De Paolis L., Bourdot P., Mongelli A. (eds) *Augmented Reality, Virtual Reality, and Computer Graphics.* AVR 2017. Lecture Notes in Computer Science, vol 10324. Springer, Cham.
[11] Y. Du, S. Liu, L. Feng, M. Chen, J. Wu, Hand Gesture Recognition with Leap Motion, arXiv:1711.04293 (12th November 2017) https://arxiv.org/abs/1711.04293.
[12] R. McCartney; J. Yuan; and H-P Bischof, "Gesture Recognition with the Leap Motion Controller" (2015). Accessed from http://scholarworks.rit.edu/other/857.
[13] I. A. Grout, Hand Motion and Gesture Control of Laboratory Test Equipment Using the Leap Motion Controller, *International Science Index, Electronics and Communication Engineering* Vol:11, No:11, 2017 waset.org/Publication/10008085.
[14] K. de Greef, E. van der Spek, T. Bekker (2013) Designing Kinect games to train motor skills for mixed ability players. In: Schouten B., Fedtke S., Bekker T., Schijven M., Gekker A. (eds) *Games for Health*. Springer Vieweg, Wiesbaden.

Nicholas Lambert is the Head of Research at the Research Office, Ravensbourne, North Greenwich in London, UK. He works across the areas of digital humanities and digital projection, with interests in immersive imaging systems and large-scale interactivity. He holds a Doctorate in Philosophy from the University of Oxford and a BA (Hons) in the Art and Archaeology of Asia and Africa from the School of Oriental and African Studies, University of London. He is a Member of the British Computer Society and Chair of the Computer Arts Society.

Seungyeon Ryu is the Creative Director at DoubleMe, inc. She has degrees from Imperial College London, Master of Science (MSc), Dyson school of Engineering(Innovation Design Engineering); 2013 – 2016; a Double master's degree in RCA and Imperial College London Royal College of Art Master of Arts (MA), Innovation Design Engineering 2013 – 2016. She did her Bachelor of Fine Arts (BFA), Product Design at 홍익대학교 / Hongik University 2007-9, where she was awarded a merit scholarship.

Mehmet Mulla is the Research Associate at the Ravensbourne Research Office. He is a Designer/Developer with a strong and dynamic interest in the various aspects of Multimedia, including meeting the Usability and Accessibility needs of the user in addition to the Research and Development aspects of project work. He holds an MA in Communication Design from Ravensbourne (2015-17), where he also won the Stationers' Bursary; and a BSc Multimedia Solutions degree from London Metropolitan University (September 2007 – June 2011) where he was awarded the prize for Best Undergraduate Multimedia Student

Albert Kim is the Founder and CEO of DoubleMe, Inc. (San Jose CA) which provides a revolutionary 3D capture system, HoloPortal, that converts 2D videos into dynamic 3D models in real-time for various 3D content markets (e.g. game, 3D animation, VR/AR, 3D printing). Prior to this, he was Founder and CEO of Zenitum, Inc. (2004-2013) and Wiz Information Technology, Ltd., CO. He holds a Master of Science in Computer Engineering from Northwestern University and a BSE in Computer Engineering from the Ohio State University.