Evaluating Real-Time Hand Gesture Recognition for Automotive Applications in Elderly Population: Cognitive Load, User Experience and Usability Degree

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Abstract— **Driving a car represents a crucial aspect to keep independence, social life and wellbeing for elderly people. Due to the age-related cognitive decline, solutions aimed to help older adults to interact easily with the vehicle and to control the car sub-systems are required. Thanks to the technology advancement, a number of interaction modalities are available, including touch, voice and, most recently, gesture control. Systems based on gesture control allow the subjects to interact with the vehicle sub-systems (i.e., vehicle navigation tool) through easy gestures, thus avoiding the subjects to be distracted while driving. This represents an interesting feature for elderly people who often show limitations in attention. On the other hand, learning the use of new technologies, such as a new interaction modality, as for the gesture control based systems, could represent a critical issue, in particular for elderly people who often suffer of memory problems. The current study aims to investigate the usability, user experience and mental workload associated with the first usage of a new developed prototype of an in-vehicle system, based on gesture control, for elderly people. Results showed that a low usability degree, as well as a quite high mental workload, is associated to the usage of the proposed prototype. The inclusion of other interaction modalities, such as voice and touch controls, as well as the improvement in the gesture control system, i.e., by reducing the number of gestures needed, is required in future releases of the developed prototype.**

***Keywords-** Ageing; Elderly; Mobility; HMI; Human Machine Interaction; Gesture control; Usability; User experience*

I. INTRODUCTION

The European population estimated in 2017 is about 511.8 million people, and 19% are older adults aged 65 and over (Eurostat). The life expectancy increase has brought great revolutions in the social and cultural spheres, and new challenges in relation to the health and well-being of older population.

Cognitive decline and brain aging is one of the older adult's challenges. Some seniors maintain excellent cognitive functions up to 70 or 80 years, others show signs of cognitive decline already in their 60s. Attention, processing speed [1] and episodic memory [2] represent the mostly aging affected cognitive functions with dramatic consequences on the daily tasks performances, such as driving [3]–[5]. A prerequisite for driving is the integration of high-level cognitive functions with perception and motor functions. The cognitive functions involved in driving are divided attention, processing speed, visual perception, short-term memory, working memory and episodic, semantic and procedural memory [6]–[8]. The age-related decline of these abilities in older drivers leads to difficulties of handling trafficked intersections and high speed roads, noticing the nearby upstream signals, negotiating wide multi-lane carriageways, etc. [7]. For example, due to the age-related decline of cognitive abilities, many of European seniors consider driving a car a stressful task. Furthermore, the UK Department for Transport research suggests that drivers aged between 60 to 69 had in average 18.8 crashes casualties per billion miles driven [9]. This number significantly increases to 56.7 casualties for drivers older than 70 years.

Reaching the grocery shops, the neighborhood facilities, or participating in community social events constitute essential needs for an older adult; therefore, the main challenge of nowadays society is to preserve the driving ability of older population. Maintaining a good mobility is vital and highlights the importance of developing innovative solutions that will help the ageing population to feel confident in driving safely. In this context, the design of future in-vehicle interfaces should take into account older drivers' needs and capabilities by increasing the safety and the comfort of elderly people. Intelligent Transport Systems, including in-vehicle navigation systems (i.e., tools that use geographical information to give feedback and support to drivers) can provide older drivers with increased confidence, and potentially deter them from taking risky behaviors [10]. In addition, new human-machine interfaces should be more accessible without requiring long periods of learning and adaptation. They should also provide more natural human-machine interaction avoiding overloading the mental abilities of older drivers.

As described in Myron Krueger's book Artificial Reality (1993), "natural interaction" means voice and gesture [11]. The voice control of in-vehicle systems is seen as an extremely desirable feature and potentially safe application for older adults, allowing to drive without requiring visual attention [12]. Similarly, in the last years, hand gesture control has gained popularity due to the potential reduction of the visual load and visual distractions associated to its usage while driving. In fact, systems based on gesture control are able to distinguish hand movements while giving correspondent reaction and vocal feedback (i.e., answer the phone, send messages, listen the desired music) without diverting the attention from driving. Furthermore, gesture control does not limit the autonomy and safety of the driver, while reducing the errors in driving.

An innovative prototype of Human Machine Interface (HMI) system based on gesture control has been realized within the H2020 European project "SILVERSTREAM". It has been specifically designed to help elderly people while driving, avoiding unambiguous and problematic interactions.

The objective of the present study was to investigate various aspects of the proposed HMI system by assessing its suitability for the elderly people through an evaluation of user expectation, user experience and usability, as well as an assessment of the mental workload associated with its usage.

The paper is organized as follows. An overview of the system, including the hand tracking device, as well as the sample population and acquisition protocol description are reported in section II. While section III provides the experimental results, the discussion has been provided in section IV. Finally, the conclusion and possible future works are reported in section V.

II. MATERIALS AND METHODS

In the following sections an overview of the system as well as of the sample population and experimental activities along with the data analysis plan has been provided.

A. *System*

The tested system consisted of the following components:

- **Hand tracking device** (Leap motion controller, Leap Motion, Inc., USA): a small USB peripheral device which use two monochromatic IR cameras and three infrared LEDs to track the hand gestures and recognize the fingers movements (Figure 1a);
- **Laptop** (Notebook F302LJ, ASUS) where the developed software for vehicle management (i.e., home, settings, radio, car navigation, etc.) has been installed (Figure 1b);
- **Monitor** (FA1013/S 10.1 inches, Lilliput) (Figure 1c);
- **3D mouse** (Space Mouse Compact, 3Dconnexion, Germany), which includes an internal 6 degrees of freedom sensor allowing to zoom and rotate in an intuitive manner thanks to simple movements. (Figure 1d).

The above-mentioned components have been hardware connected and represent the tested "HMI system".

B. *Hand tracking device*

The hand tracking device (Leap motion sensor) represents the core of the tested system since it allows the software remote control by tracking the hands and fingers movements (i.e., "gestures"). The device consists of two IR cameras and three infrared LEDs directed along the y-axis with a field of view of about 150 degrees (Figure 2).

Figure 1. System components

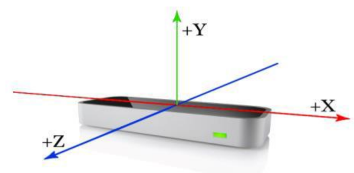

Figure 2. Leap motion sensor coordinate system

The effective range covered is from approximately 25 to 600 millimetres above the device. Position of hands and fingers is provided thanks to a model of human hand included in the linked proprietary software. The software recognises certain movement patterns (i.e., gestures), which indicate the user's intention or command. The recognized gestures could be clustered in the following subclasses:

- Circle Gesture (Figure 3a)
- Swipe Gesture (Figure 3b)
- Back Gesture (Figure 3c)
- Grab Gesture (Figure 3d)
- Hand Key Tap Gesture (Figure 3e)

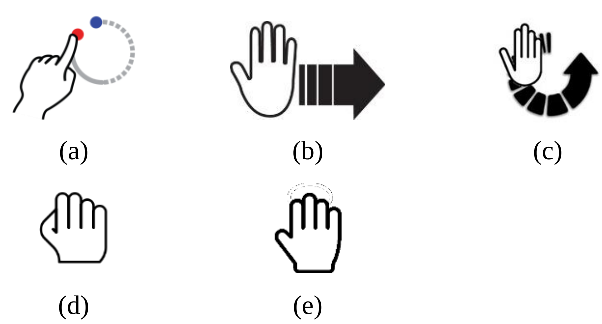

Figure 3. Recognized gestures

C. *Sample Population*

A sample of thirty subjects aged over 65 years old took part to the study. Subjects were recruited from a previous clinical study ("Epidemiological study on a sample of elderly subjects with subjective complaints of memory") approved

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by the Ethics Committee of San Raffaele Hospital (HSR), in Milan. All participants provided informed written consent, edited in accordance to the Declaration of Helsinki [13].

D. Experimental Setup

Subjects have been invited at the HSR facilities to take part to the experiment. A room, suitably furnished with the HMI system, has been chosen as scenario for the experiments. A large digital screen has been used during the experiments to show the gestures to the participants and the requested tasks (Figure 4).

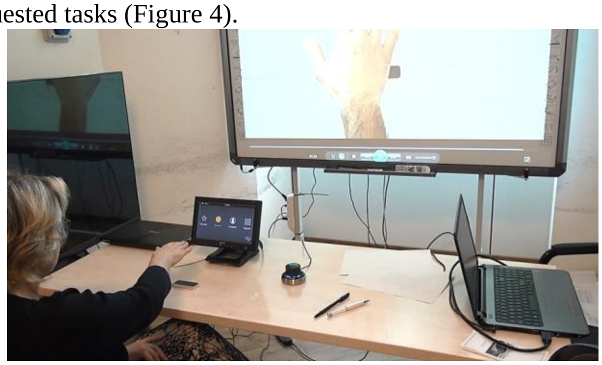

Figure 4. Experimental setup

Two researchers, i.e., testers (a neuropsychologist and a bioengineer) were involved in the experiments.

E. Acquisition protocol

Before starting the experiment, participants have been interviewed through "Preliminary Interview" by the neuropsychologist regarding their level of confidence in using technological devices, in both general and automotive context. Then, the following experimental protocol (lasting about 1h and half) has been carried out for each participant:

- **Cognitive assessment** through the Mini Mental State Examination (MMSE);
- **Demonstrative video** illustrating the main features of the HMI system (i.e., setting, gestures, etc.);
- **Subjective expectations assessment** through the user experience evaluation questionnaire ($SUXES_i$) [14], to assess the user expectation about the proposed system;
- **Familiarization period** in which participant was invited to freely use the HMI system;
- **Usability test** where the participant was asked to carry out a number of tasks commonly performed in a vehicle (e.g. selection of an audio track through the HMI system or regulating the temperature) through the gestures shown in the demonstrative video and reported in Figure 3;
- **Subjective usability assessment** through the System Usability Scale (SUS) questionnaire [15], [16], to evaluate the post-test perceived usability of the system;
- **Subjective experience assessment** through the $SUXES_f$ questionnaire, to assess the user experience after the system usage.
- **Mental workload assessment** through the NASA [17] Task Load Index (TLX) questionnaire.

Finally, the neuropsychologist interviewed the participant by means of "Final Interview" to collect his/her impressions about the tested system focusing in particular on: ease of use, workload associated and main difficulties found.

F. Methods

All the above-mentioned surveys have been already validated and published in literature and represent gold standard methodologies for assessing the following aspects of interest: cognitive functions (MMSE), users' expectations and users experience (SUXES), the system usability (SUS) and mental workload (NASA) associated to the HMI system use.

The usability test has been performed according to the standard guidelines [18], which requires the participant to perform a number of task using the tested system. During the test, the tester observed the participant without formulate any question while collecting some quantitative variables (i.e., required time for the tasks, number of attempts and number of errors). These variables were useful for the objective evaluation of usability of the HMI system.

G. Data analysis

1) Preliminary Interview

The general knowledge of the technology along with the confidence in the usage of the three more common interaction modalities in automotive context (voice, touch and gesture) have been investigated for each subject. A frequency analysis has been performed considering the answers obtained.

2) Cognitive assessment

Each participant's MMSE outcome score was corrected for age and education and compared with the pathological cut-off of 23.60/30.

3) User expectation and user experience

According to [14], for each subject, two different scores associated to the user expectations (the "desired" and the "accepted" level) have been identified through the $SUXES_i$. Instead, a further score associated to the user experience (the "perceived" level) has been computed through the $SUXES_f$. Based on such scores, two different measures have been computed:

- Measure of Service Superiority (MSS): difference between the perceived level and the desired level;
- Measure of Service Adequacy (MSA): difference between the perceived level and the accepted level.

Those measures allowed the estimation of the gap between expectation and experience. If the experience is in the range of expectation, MSS value is negative and MSA is positive.

4) Usability of the system

According to the level of agreement selected for each statement of the SUS questionnaire, a SUS score has been computed for each participant. According to [15], [16] depending on whether the reported SUS score was greater or smaller than 68, the system was defined usable or not.

In addition, in order to evaluate the subjects performances in using the gesture control, quantitative scores (i.e., objective scores) collected during the usability test (number of errors) have been analyzed for each gesture.

5) *Mental workload*

An overall score of workload in a 100-point scale based on weighted average of six sub-scales (Mental Request, Physical Request, Temporal Request, Performance, Effort and Frustration) has been obtained for each subject.

III. RESULTS

In the following, the main results of the study have been provided.

A. *Sample Population*

Subjects' characteristics (age and schooling) are reported in Table I.

TABLE I. PARTICIPANTS' AGE AND SCHOOLING

Gender	**#**	**Participants' characteristics**	
		Age [years]	*Schooling [years]*
Female	17	70±4	12±3
Male	13	73±3	14±3

B. *Preliminary Interview*

Subjects' knowledge of the technology (clustered in three main categories: poor, medium and high according to the self-reporting score) has been shown in Table II.

TABLE II. KNOWLEDGE OF TECHNOLOGY

	High	Medium	Poor
Knowledge of technology	40%	33%	27%

Subjects' knowledge of the interaction modalities (touch, voice and gesture control) has been reported in Figure 5.

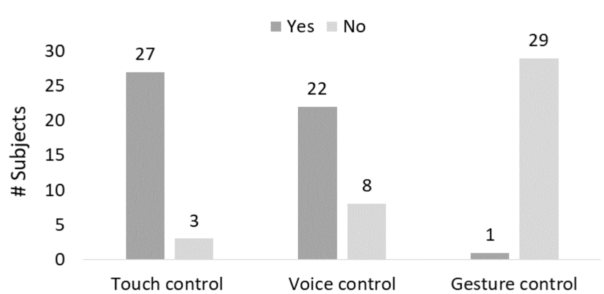

Figure 5. Knowledge of interaction modalities

Only one subject reported the knowledge of gesture control, while none of them had ever had the chance to try it.

C. *Cognitive assessment*

All the subjects reported no cognitive impairment (MMSE<23.60). The subjects reported the following scores: MMSE=26 (n=1); MMSE=27 (n=3); MMSE=28 (n=7); MMSE=29 (n=7); MMSE=30 (n=12).

D. *User expectation and user experience*

The values of MSS and MSA computed for each subject are reported in Figure 6.

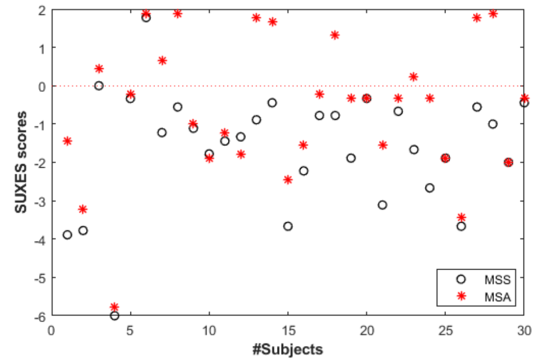

Figure 6. Measure of service superiority (MSS) and Measure of service adequacy (MSA)

As shown in the figure, for all the subjects, except two, the perceived level was lower than the desired one (MSS<0) but, for ten of them, higher than the accepted one (MSA>0). The experiences resulted to be in the range of expectations (MSS values negative and MSA values positive) for eight subjects.

E. *Usability of the HMI system*

The SUS scores are shown in Table III.

TABLE III. SUS SCORES

SUS score	**Participants**
> 68	27 %
≤ 68	73 %

According to the table, only 27% of subjects reported a SUS score >68 meaning that the system was judged usable. The Acceptability level has been reported in Table IV.

TABLE IV. LEVEL OF ACCEPTABILITY ACCORDING TO THE SUS SCORE

Acceptability	**Range**	**#Subjects**
Not acceptable	0-50	11
Marginal-low	50-62	9
Marginal-high	62-70	2
Acceptable	70-100	7

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The usability of the system has been also analyzed considering the number of errors reported for each gesture during the usability test, as reported in Table V.

TABLE V. NUMBER OF ERRORS DURING THE USABILITY TEST

Gesture	Requested repetitions (#)	Errors (#)	
		mean	std
Circle Gesture	60	3	± 9
Swipe	600	4	± 5
Back	**180**	**8**	**± 10**
Grab	60	1	± 2
Hand Key Tap	390	4	± 5

The higher number of repetitions for some of the gestures (Swipe, Hand Key Tap and Back) are related to the tasks flow (i.e., made a phone call, select one music track, etc.).

F. *Mental workload*

The overall workload has been computed for each subject and reported in Figure 7 together with a box and whisker to graphically summarize the data.

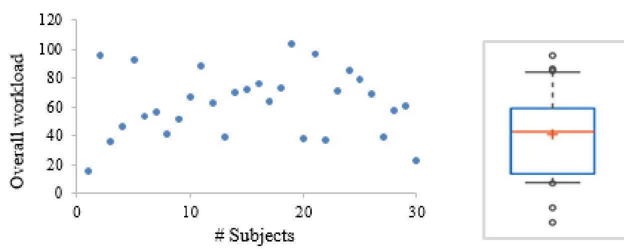

Figure 7. NASA TLX score

The workload experienced by participants for each dimension investigated by NASA TLX questionnaire has been shown in Figure 8.

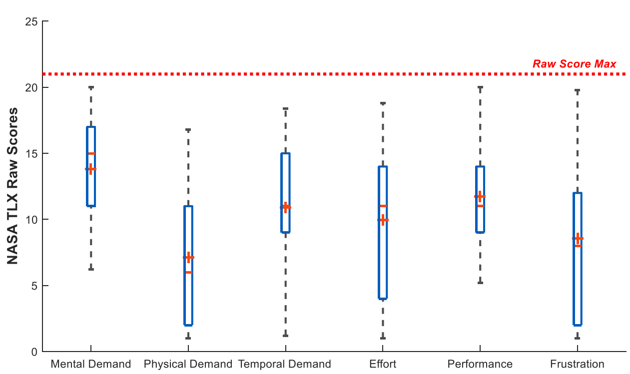

Figure 8. NASA TLX raw scores

The NASA dimension characterized by a higher workload resulted to be the mental one.

G. *Final Interview*

Subjects' impressions about the ease of use of the HMI system, the associated workload and the difficulties found during its use have been reported in Table VI.

TABLE VI. PARTICIPANTS' FEEDBACK

	Ease of use	Workload		Difficulty	
	Easy	***Physical***	***Cognitive***	***Memory***	***Association***
Yes	13 %	23 %	63 %	23 %	20 %
No	87 %	77 %	37 %	77 %	80 %

Subjects reported a low perceived ease of use (87%) and cognitive effort has been noticed (63%). Instead, only few subjects reported high physical workload (23%) and memory (23%) or association (20%) difficulties.

IV. DISCUSSIONS

The purpose of this work was to verify the appropriateness in terms of user experience and usability of the proposed HMI system to the elderly specific needs.
All subjects reported good cognitive performances on MMSE test. Most of them (73%) considered the HMI system not usable and their experience was below the range of expectations while the 63% of participants complained the cognitive workload needed to accomplish the tasks required during the test. Moreover, most participants (87%) reported that the HMI system was very difficult to learn even if only a small part of them declared, at the end of the test, to have experienced memory (23%) and association problems (20%). It is clear that such problems can lead to a lower accuracy of gestures execution, which consequently appears in negative emotions, as irritation and frustration, during the interaction with the system.

The advantage of using a gesture control-based system in automotive context does not seem to be confirmed by participants: indeed, the gestures have not been so assimilated to allow their execution without looking at the screen. A proper learning appears therefore fundamental to ensure a better experience with the proposed system and it can be done simplifying the most critical gestures as the back one, as resulted from the usability testing and, at the same time, providing more time to make the elderly more familiar with this new kind of technology.

V. CONCLUSIONS

The results obtained in the present study suggested that the proposed HMI system, based on gesture control, is difficult and not well perceived by older population. In addition, long time to ensure a correct and complete learning for properly using the system resulted to be needed.

However, it is important to highlight that the present generation of elderly has not so much familiarity with the technology contrary to the future one. Therefore, the

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integration with the best-known touch and voice controls, as well as an accomplished learning leading to an automatic execution of gestures should be provided to make the tested HMI system a useful tool for the forthcoming generations of elderly.

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