Human Machine Interface: A review for future applications in train driving

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The paper deals with the description of preliminary research work based on extended investigation focused on categorized Human Machines Interface (HMI), describing their technical approaches and emerging operational issues. The study aims at reviewing and analysing HMI, their design and control systems currently on the market or in experimental operation. The analysis acts as a review manual on HMI technologies to design customized HMI and analyse the technologies used or tested in the present technological scenario. The paper starts by addressing the systems developed by manufacturers of surface vehicles outside railway field: trucks, cars and ships. It follows with the performances of simulators developed for various transport systems: rail, cars, aviation and integrated solutions. Finally, the focus is on the comparative analysis of the performances of supporting tools for train driver's assistance, a synthetic analysis of results and the organization of the survey among drivers to check expectations and acceptance of potential solutions.

1. Introduction

The field of automation is gaining increasing interest from research in various application fields, along a path began in the 1920s, with the first radio-controlled vehicle. Today, there is an increasing interest of companies to invest towards large-scale adoption of self-driving vehicles. Studies on the user experience aboard autonomous or semi-autonomous vehicles are in close connection with the question of trust in the Human Machine Interface (HMI). In particular, in a semi-automatic vehicle, the design of HMI must give awareness of driving situation, to regain effectively the control, whenever called upon to intervene. Within the CARBODIN research project, co-funded under the Shift2Rail Programme, the aim is meeting the expectations of train drivers and staffs with HMI automatic functions to arrive to progress towards their introduction. The focus is on the identification of required inputs and available outputs of various systems and operator preferences, further investigated by dedicated surveys on potential HMI configurations to design new drivers' cabins and build a virtual mock-up with immersive technology using specific banks of sounds and gestures.

2. Path towards the future train drivers cabin

The railway transport systems in general are historically less sensible than others are to the pilot application of disruptive technologies. This is firstly due to the combination of the rigorous intrinsic safety requirements qualifying it and the general longer technical life of its components and the system itself. Therefore, in view of the progressive introduction of the innovations supporting the train driving functions, the CARBODIN project [1] aims at joining the identification of the most promising technological driving supports with the expectations of train drivers or other railway operator staffs about HMI in future cabins. The basis of this are 360° surveys about potentially applicable mature technologies on one side as well as preferences and efficiencies of possible new innovative configurations on the other side, by taking into account the key role of human factors, particularly in the design of input and output sensors, gestures and supporting acoustic and visual signals.

3. State-of-the-art in driving automation

Within the framework of what discussed above, the progressive introduction of the innovations supporting the train driving functions, started from the analysis of systems developed by manufacturers of surface vehicles, namely trucks, cars and ships. The reasoning behind this choice is that for the application in railway operational environment, almost mono-dimensional due to the guidance of rails, the applications in other surface transport systems have a higher applicability potential than those tested or applied in typical three-dimensional operational environments, such as aviation and the same is for the speed ranges. Nevertheless, aeronautical applications remains in the scope of the study as potential sources of solutions for specific interfaces, such as sensors, sounds and gestures used in real driving systems and simulators.

A systematic review of potentially promising systems is in [2]. Table 1 provides with an overview of the automation functions performed by some systems on the market, in view of a potential use in the trains driving functions.

Table 1. Overview of investigated systems implemented in various typologies of vehicles

Name	Developer	Operating features	Vehicle
MAN PLATOONING	MAN, DB SCHENKER	Driver assistance and control with hand always on the wheel	Trucks
HIGHWAY PILOT	DAIMLER	Full autopilot with manual selection	Trucks
AUTOPILOT 2.5	TESLA	Autopilot's assistance and control with hand always on the wheel	Cars
iNEXT-COPILOT	BMW	Co-pilot switchable to autonomous driving manually or by voice	Cars
DRIVE PILOT	Daimler Mercedes-Benz	Fall-back-ready user resuming manual driving by steering, braking, accelerating or switching off manually	Cars
THE FALCO	ROLLS ROYCE, FinFerries	Full automation with ergonomic HMI, control levers and touch screens for call up and control	Ships

4. State-of-the-art in driving simulation

Another important source of technological solutions applicable to rail cabins comes from the professional simulators. Also in this field, surveys and analysis focuses on the surface transport systems and covers purely rail vehicles applications, road vehicles and integrated systems [3] [4] [5], as summarised in Table 2.

Table 2: Overview of investigated simulators

Name	Developer	Operating features	Vehicle
PSCHITT-RAIL	European Regional Development Fund, Investing in your future; Région Hauts-de-France	Movements capture by eyes trackers and physiological measurement sensors	Trains
SPICA RAIL	utc	Increasing disturbances to evaluate human behaviours and supervision platform	Trains
OKTAL SYDAC	OKTAL >> SIMULATION IN MOTION; SYDAC	Replicas of the cab to ensure realistic driving experiences	Trains
IFFSTAR-RAIL	IFSTTAR	Reproduction of driving and rail traffic supervision	Trains
IFFSTAR TS2	IFSTTAR	Impact of internal and external factors on driver behaviours and fixed-base cab HMI	Cars
NDIVIA DRIVE	NVIDIA	Interface among environment, vehicles and traffic scenario by open platform sensors	Cars
VRX-2019	ANSYS; OPTIS	Autonomous vehicle experiencing feelings of cockpit's HMI by advanced sensors	Cars
MISSRAIL	Université Polytechnique HAUTS-DE-FRANCE	Automated driving assistance combining accident scenarios including pedestrians, trains and cars with human factor control	Integrated

Simulators represent a key starting point for the design of innovative driving functions, as well as for the safety of traffic supervision within railway systems [6] [7] [8] and interactions with other transport networks [9] [10]. Their benefits are the possibility to test, in advance, applicability and capability to generate improvements of operational performances, to obtain information about the future design and reduce the deployment costs.

5. Emerging gesture technologies

From the analysis on driving automation and simulation systems, as well as from a dedicated literature review, emerged a large set of technologies available on the market to control devices by gestures. A not comprehensive list of them is in Table 3.

Starting from analyses developed in a similar study [11], Table 4 summarize the results of a comparative Strength, Weaknesses, Opportunities and Threats (SWOT) analysis focused on the most relevant features differentiating three of the most promising gesture control devices: *KINECT* (by *Microsoft*), *LEAP MOTION* (by *Ultrahaptics*) and *MYO BRACELET* (by *Thalmic Labs*). Due to the recurrence for all systems, the table does not include general threats, such as the lack of definition of a process for the recovery of gesture control intrusion. Moreover, all the investigated systems investigated have reached, in their respective fields, Technology Readiness Levels (TRL) variable among TRL7 (System prototype demonstration in operational environment), TRL8 (System complete and qualified) and TRL 9 (Actual system proven in operational environment).

Table 3: Overview of control devices by gesture

Name	Developer	Operating features
DEPTHENSE CARLIB	SONY	Controlling movements of infotainments by hand
EYEDRIVE GESTURE CONTROL	EYELIGHTS FOR YOUR CAR	Recognizing hand gestures while driving to control devices by infrared sensors
HAPTIX	haptx	Recognizing classical hand movements and building a virtual mouse to control screen interface by webcams
KINECT	Microsoft	Capturing body or hand movements to control devices by webcams
LEAP MOTION	ultrahaptics	Recognizing hands or objects movements for virtual reality by infrared light, 3D micro-cameras
MYO BRACELET	THALMICLABS	Detecting hands or fingers movements to control interfaces with electrical activation of muscles
SOLI	Google	Identification of movements of fingers or body by mini-radar
SWIPE	FIBARO	Reading hand motions in front of a small contactless tablet for home automation purposes
XPERIA TOUCH DEVICE	SONY	Tracking proximate hand gesture via the smartphone camera

Table 4: Differential items in SWOT analysis of selected control devices by gesture

Name	Developer	Strengths	Weaknesses	Opportunities	Threats
KINECT	Microsoft	1) Identification of body motions	1) Operational difficulties in restricted space 2) Interference movements-sensor	1) Combination of gesture control with facial/voice recognition	-
LEAP MOTION	ultrahaptics	1) Identification of hands/fingers movements 2) Low price 3) Light weight	1) Deep training need 2) Interference movements-sensor	1) Combination of infrared light and cameras	-
MYO BRACELET	THALMICLABS	1) Gesture detection of bracelet wearer 2) Light weight	1) Deep training need 2) Few identified movements	1) Combination of physiological detection with gesture control	-

6. Survey on train drivers acceptance

The eminent role of the human behaviour in the field requires integrating the ongoing activity on the promising technologies and solutions with a survey directly involving drivers about their expectations and acceptance of potential solutions.

The objective of this first survey is to select the key targets of the train cab of the future and the interactions should be possible in this driver's cab by involving the drivers themselves from the earliest stages of the creation of these new systems. The envisaged automation is willing to assist the driver in providing the best possible user experience, adapted to the constraints of the job and integrating the latest technologies for more comfort of use and efficiency.

The investigated technologies are applicable to various means of Action (A) and Information (I) that would enable the driver to keep informed of the state of the train, such as:

- AUDIO: Voice control of the system (A) and audible notification (I);
- TOUCH SCREEN: Use of touch screens (smartphone, tablet, etc.) for entering commands (A) and reading information (I);
- GESTURE: Gestures recognition to act on the system without contact (A);
- VISUAL: Projection of information into the driver's field of vision and accessible through a Head-Up Display (HUD), without leaving the lane of sight (I).
- HAPTICAL: Use of manipulator to add force feedback functions, assist the driver, accompanying or resisting the driver's movements for actions control (A) and information on speed (I).

Table 5 summarizes the potentially covered drivers' tasks included into the survey.

Table 5: Drivers' tasks potentially affected by the use of the selected innovative technologies

Key elements		**Auxiliary systems**		**Additional devices**	
Groups	**Tasks**	**Group**	**Task**	**Group**	**Task**
Situation awareness	Dead Man's Switch	Station stop	movement authorization	Lighting	Instrument brightness
	Signalling		Stopping		Cabin lighting
Speed regulation	Train Protection & Warning System		Reverser	Comfort systems	Sanitary
	Cruise control	Accessories	Sand spraying		Audio Announcement
	Engine Throttle		Windshield cleaner		Passenger's energy
	Brake		Wiper		Climate control
Flow Management	Door / Bridging plate		Headlight		Lighting
Alarms systems	Whistle		Defrosting		Sound system
	Emergency brake	Management power	Change traction mode	Configuration	Start / Stop
	Emergency stop button		Change voltage		Train settings
	Alarm systems		Pantograph		
	Pantograph				
	Passenger alarm signal				

The survey, carried out in the first months of 2021, involved 1689 drivers from 15 different European countries.

Statistical analyses will follow, developed by means of the following techniques:

- *Boxplot* graphically depicting groups of numerical data through their quartiles, based on Action (A) / Information (I) and group of tasks depending on technologies);
- *Multiple Correspondence Analysis* (MCA) to detect and represent underlying structures in a data set (Age, Profession, Gender, Nationality, Country Network, Train Type).
- *Hierarchical Clustering Analysis* (HCA) to build a hierarchy of clusters.

7. Conclusions

All the investigated systems have reached in the respective application fields TRL7, TRL8 or TRL9. Therefore, they appears highly reliable in view of potential applications in the design of future trains' drivers' cabin. The experience matured in the analysis and selection process and in the survey with drivers demonstrated that many of them are well in line with the expectation setup within the CARBODIN and the related PIVOT2 Shift2Rail funded projects. They aim at reaching Technology Readiness Levels variable among TRL5 (Technology validated in relevant environment), TRL6 (Technology demonstrated in relevant environment) and TRL7 (System prototype demonstration in operational environment) [1].

The next research developments, based on the results from the first round of surveys, are progressive refinements that will allow at: 1) eliminating systems and technologies not adapted for innovative driving cabin and selection, based on the needs from operators, 2) implementing promising HMI in virtual mock-up demonstrator for further testing by professional drivers on a simulator.

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