Title:
System based on Abstract Prototyping and Motion Capture to Support Car Interior Design

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Introduction:
Comfort, ergonomics, habitability are aspects that car interior designers have to take into account during the development of new cockpits. Even though consolidated rules lead the design in this sense, they do not suggest in any way how making significant changes to car interiors according to the users' needs. Human perception of the internal space of a car relies to several psychological as well as physical factors [11] and their assessment is often very difficult to carry out. Besides, performing evaluation tests, aiming at assessing these factors, implies making cockpit prototypes with which users have to interact and, consequently, the results of these tests cannot help designers during the design process. To anticipate the execution of these evaluation tests, car manufacturers are currently using Virtual Reality technologies to simulate the cockpit before making the first physical prototype. Although several studies have demonstrated the effectiveness of this approach [2][8][10], the results of these tests still provide suggestions useful to improve a cockpit, which has been already substantially designed.

The study described in this paper presents a system aiming at supporting the generation of car cockpit design at the very early stage of the design process. In particular, the paper proposes a study focused on the issues related to the passenger's seat, which is a car interior element that could gain many benefits from this approach. In fact, passenger's seat is usually designed as the symmetrical counterpart of the driver's seat even though passengers have highly different needs in terms of comfort, safety and freedom of movements, if compared to the drivers. The main objective of this research was the development of a system able to record passenger's movements during the execution of actions within the car cockpit. The system has been developed by integrating Abstract Prototyping technique with Motion Capture System. A systematic procedure to manage and to synthesise motion data has been also implemented so as to make these data directly available as a generative input for the concept design process. The paper describes also a testing session conducted with users to evaluate the developed approach. Subsequently, the outcomes of the testing sessions have been discussed, highlighting benefits and limitations, while, in the final remarks, future research possibilities and other application fields are presented.

Main idea:
The idea behind the proposed research is to provide the designer with a system to quantitatively capture passengers' habits and consequently nurture the concept of a new passenger's seat that best fulfil their needs. To identify the most characterizing habits of car passengers, a preliminary test in field-research modality has been conducted by designers and it has dealt with the observation of users in a real context. This preliminary observation was meant to identify the actions [4], corresponding to users' needs, to be further explored in the study. The observation was carried out with 9 participants,

5 male and 4 female, video-recording them with a frontal GoPro© [6] camera and one hand-camera in the back seats. Participants were brought on a medium-length journey (average 40 minutes), after which they were interviewed about the level of comfort, their needs and their expectations. Through these first results, four actions were identified: (1) the assessment of comfort in posture; (2) the interaction with either people or objects in the back seats; (3) the placement of personal items, such as bags, coats etc.; (4) the interaction with smart devices.

Being the actions correlated to passengers' movements, the second phase of the research has consisted in quantitatively capturing and synthesizing these movements during the execution of these actions. To capture these movements in a systematic way, a prototype of the passengers' cockpit area was needed, but, being in a conceptual stage, the final design of the cockpit area has still to be generated and, hence, was not available for physical prototyping. For this reason, the research proposes to make use of the Abstract Prototyping technique to physically simulate the cockpit passenger's area. Abstract Prototyping technique [7] involves the creation of a rough prototype of an artefact, which is used to run the user tests. The prototype should represent the artefact in a synthetic way, while avoiding realistic details. In this way, the participants to the test will be encouraged to undertake a creative and participatory attitude [1]. Abstract Prototyping allows making the ideas tangible, quickly and cheaply so that they can be tested and evaluated by others. In this research the implemented Abstract Prototype reproduces the rough geometry of the cockpit passenger's area while a real seat was located within this area.

To capture the users' movements, instead, a motion capture system has been used, in particular 6 Flex-3 cameras by OptiTrack© [9] have been placed around the cockpit. Considering how the Abstract Prototype had been designed, this configuration is the best to prevent occlusions in the acquisition. The passengers' movements have been tracked by using the Rigid Body Tracking modality. This involves capturing only selected parts of the human body, and can be carried out by using some wearable devices (rigid bodies) covered with retro-reflective markers. Rigid Bodies are defined as clusters of reflective markers in a unique configuration, which allows them to be identified and tracked in a cloud of 3D points. It is possible to track multiple Rigid Bodies at a time in full 6 degrees of freedom (position and orientation, 6DOF). For this study, we have identified 8 areas of the human body to track (head, arms, chest, knees and feet), each of which needed a corresponding wearable marker-sets.

The goal of the system was to obtain a 3D capture of passengers' movements while simulating and recalling their personal experiences as passenger beside the driver and executing the actions identified in the preliminary test. The expected output is a set of motion data that constitute a volumetric 3D model representing the (desired) space of interaction for passengers. The data acquired during the tests needed to be post-processed in order to be meaningful for designers, and to be represented in a way and in an environment that are familiar to them.

Testing session

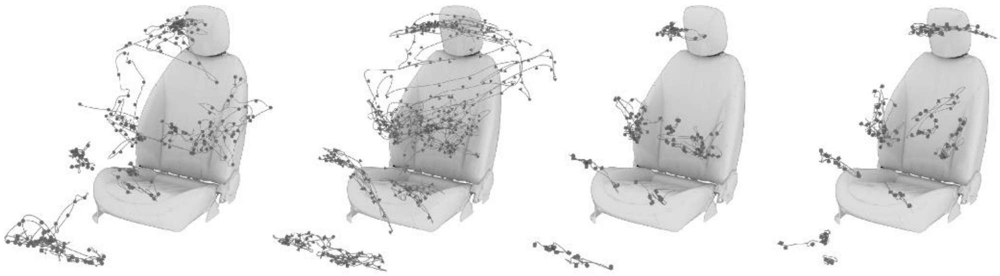
To evaluate the effectiveness of the proposed system, an evaluation test with users was organised. In particular, 9 participants (5 male, 4 female, aged 25-52) have been involved. The testing session was split into two phases: during the first phase participants were asked to recall one meaningful experience as a passenger in the car. This phase relied on the Open Interview technique, according to which people can reveal important issues and opportunities by narrating stories about their daily experiences. The second phase was, instead, conducted by using a semi-structured approach [3], by following a set of pre-determined questions to tackle the four actions causing problems as defined in the preliminary test. Accordingly, the interviewer is allowed to follow new ideas and paths of research that may be brought up during the session. The interviews were video-recorded not only to document participants' feedbacks but also to provide a reference for the subsequent steps of motion data analysis. During the tests, the users' movements and gestures inside the Abstract Prototype were captured and stored. Fig. 1 shows a user during the execution of the test.

(a) (b) (c) (d)

Fig. 1: User during execution of the four actions in the testing session: (a) researching of maximal comfort, (b) positioning of personal objects, (c) using of smart devices, (d) interacting with the back seats.

Results

The testing session generates a big amount of motion tracking data and a specific post-processing procedure was needed to make them suitable for the subsequent synthesis. In fact, this kind of data is difficult to manage as is and, consequently, it has to be converted into a synthetic representation within 3D modelling software. The first step after completing the user tests was to treat motion tracking data in order to discard any error that has occurred in the system. The system calibration and the design of the wearable marker-sets may heavily influence the delicate phase of capturing human gestures. Yet, occlusions caused by some movement, parts to be trimmed, misidentification of markers and other accidents can take place. The second step was to extract the data from the Motion Capture system, and to make them suitable for the 3D modelling environment. The goal was to extract only the information about the position of each Rigid Body from the raw data, to create refined data sheets that can be imported in 3D modelling software tools. To automate the process, a software application was implemented to recognise the information associated with each marker-set and generate sub-files listing the (X, Y, Z) position of their centroid for each frame. Subsequently, motion tracking data have been imported into standard NURBS-based modelling software tool. In this way, numeric data is converted into Point Clouds, which represents the first step towards a meaningful visualization of data. To synthesise the data and to give a more useful representation, Point Clouds were used to generate curves since points lack of representation clarity when imported in a 3D modelling environment. After testing several curve-generation methods, the Bézier curve (degree=11) was found as the most satisfactory. Fig. 2 shows the results of the curves generated from the Point Clouds captured during the execution of the four actions identified during the preliminary test.



(a) (b) (c) (d)

Fig. 2: Results of the motion tracking data representing the four actions after the elaboration: (a) researching of maximal comfort, (b) positioning of personal objects, (c) using of smart devices, (d) interacting with the back seats.

Possible uses of the motion data

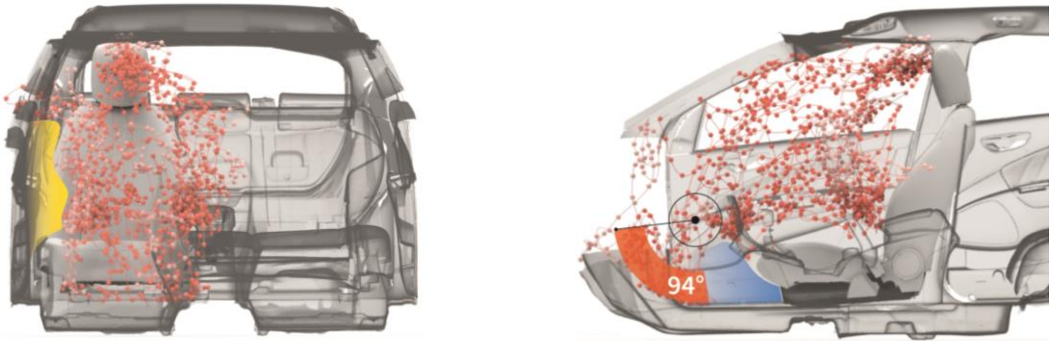
After the elaboration, the data have been used to carry out some analyses of the space occupied by the subject in the cockpit during the execution of the actions. To perform these analyses a 3D model of a cockpit of a generic C-segment car was imported into the 3D modelling software. To align the acquired data to the 3D model of the cockpit some significant points of the seat have been used as reference points. After these settings, the user of the 3D modelling software has the possibility to show and hide all the motion data acquired during the testing session. To make this operation easier, the data were clustered on different layers with different colours. Each layer relates to the data of the movements of the four actions for a single subject. In this way, the user can visualize the data in different combinations choosing between type of the action and subject (e.g. all actions of a single subject, a single action of all subjects, etc.).

The visualization of the data within the 3D modelling software allowed further identifying some areas never crossed by the subjects. These areas can be filled by using the freeform geometries provided by the modelling software. As shown in Fig. 3a, a yellow freeform geometry has been created to highlight the not-crossed area on the lateral side. This freeform geometry, for instance, could be subsequently used as a geometric reference to create a lateral support for the passenger. In addition, the measuring tools of the 3D modelling software could be used to take some specific measurements of the acquired movement data in an easy way, as shown in Fig 3b.

The possible uses of the motion data above proposed have to be considered an attempt to show the potentialities that the implemented system and the motion-tracking data can provide. Obviously, car interior designers can find several other manners to exploit these data visualizations in a way that reflects not only their personal design attitude, but also their subjective interpretation of the motion data.

Discussion

The data visualization proposed in this study gives information on the trajectories of the human movements and the areas where users interact the most. This will give the possibility to shape new concept of the passenger side of the cockpit as a negative model, i.e. using the data as a starting point for the concept generation process.



(a) (b)

Fig. 3: Visualization of the motion data relating two actions of a single subject: (a) inclusion of a freeform geometry, (b) specific measurement of the acquired movement data.

The concept design could be based on solid, reliable data (motion tracking data), merging effectiveness and style. Through this system, motion tracking data could be also coupled with interview results. These provided other interesting insights, outlining some critical issues for every action. The main asset found was the need of an area specifically designed to better integrate the passenger's needs. This involves breaking the symmetry in the car interior design, guaranteeing a larger flexibility in the movements for passengers. However, the study presents some limitations and some improvements have to be implemented. Firstly, the criteria selected to display motion data are now restricted to the position and frequency only. Actually, other possible approaches involve the creation of gesture areas, i.e. polygonal meshes generated over the Point Clouds. This process could highlight better the volume of interaction while neglecting the information on the trajectories and orientation. The integration of 3D human models, as retrieved in [5], offers another possibility of investigation. Nevertheless, the most promising prospect is given by parametric modelling software. In this way, it will be possible to display and organise a larger number of parameters, such as the speed, the orientation, etc.

Conclusions:

This paper presents a system to capture and synthesise motion tracking data with the final aim of supplying meaningful insights to support the concept generation process. The performed testing session demonstrated that human movements can be used to infer the users' personal experiences of a space. The captured motion tracking data can be used to generate 3D geometries to shape new concepts of the passenger side of the cockpit. A systematic procedure has been implemented to allow the treatment of the collected data to obtain a graphical representation, which can be easily used within standard NURBS-based modelling software. The visualization of this data within the modelling software allowed identifying and analysing the areas, which were not involved by the movements of the subjects. By presenting capture results as a three-dimensional representation, designers can actively interact with the model, while standard observation techniques only allow a passive fruition. From these analyses, designers could take inspiration to generate a new the cockpit concept according the non-standard movements executed by the car passenger.

However, while the synthesis of motion tracking data has been sufficiently addressed by this study, the designers' viewpoint should be further investigated, to understand how they could exploit this kind of data for modelling new shapes. The authors make the hypothesis that the effectiveness of the system could be validated through other case studies, with other kinds of products. All the products involving a spatial interaction seem more suitable for the aim; as for those the study of human gestures acquires more value. In this respect, a correlation between the semantics of gestures and movements can give new possibilities of interpretation. Finally, further evaluation tests would be beneficial to clearly assess the costs in terms of time and resources that the use of this system implies.

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