A Design Space for Vehicular LifeLogging to Support Creation of Digital Content in Connected Cars

Adrian Aiordăchioae
MintViz Lab, MANSiD Center,
University Ştefan cel Mare of Suceava
Suceava 720219, Romania
adrian.aiordachioae2@student.usv.ro

Radu-Daniel Vatavu
MintViz Lab, MANSiD Center,
University Ştefan cel Mare of Suceava
Suceava 720219, Romania
radu.vatavu@usm.ro

Dorin-Mircea Popovici
CeRVA Lab,
Ovidius University of Constanţa
Constanţa, Romania
dmpopovici@univ-ovidius.ro

ABSTRACT

Connected cars can create, store, and share a wide variety of data reported by in-vehicle sensors and systems, but also by mobile and wearable devices, such as smartphones, smartwatches, and smartglasses, operated by the vehicle occupants. This wide variety of driving- and journey-related data creates ideal premises for vehicular logs with applications ranging from driving assistance to monitoring driving performance and to generating content for lifelogging enthusiasts. In this paper, we introduce *a design space for vehicular lifelogging* consisting of five dimensions: (1) *nature* and (2) *source* of the data, (3) *actors*, (4) *locality*, and (5) *representation*. We use our design space to characterize existing vehicular lifelogging systems, but also to inform the features of a new prototype for the creation of digital content in connected cars using a smartphone and a pair of smartglasses.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Interactive systems and tools**; **Mobile devices**; • **Software and its engineering**;

KEYWORDS

Connected cars; Vehicular lifelogging; Design space.

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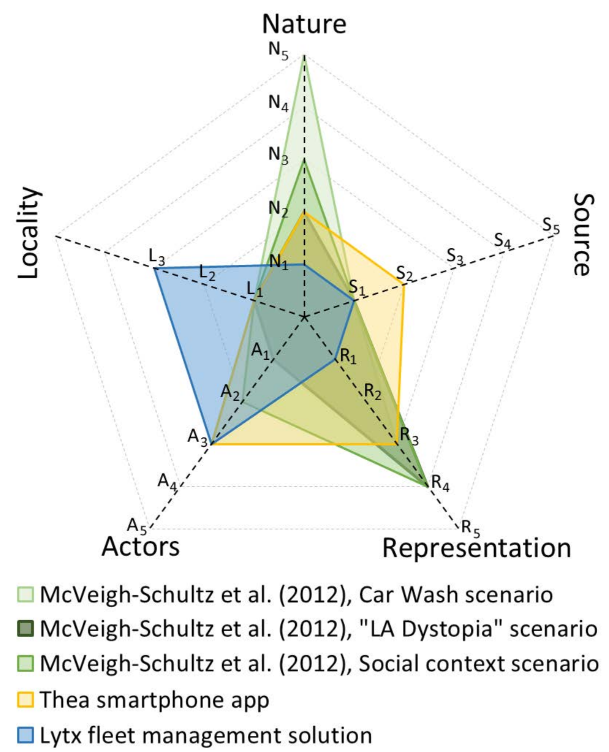

Figure 1. A visual illustration of our design space for the creation of digital content in connected cars characterizing prior work [14,16,24] using five dimensions.

1 INTRODUCTION

Connected cars come equipped with Internet access and Wi-Fi communications and, consequently, can exchange a variety of data with other devices, applications, and systems located both inside and outside the vehicle. This feature creates the premises for convenient access to real-time traffic and weather conditions [25], personalized driving assistance [19], and driver monitoring [14], among other applications.

A particular application is "vehicular lifelogging" [13,14, 16,24] that consists in collecting and storing various data regarding the driver's performance using the in-vehicle builtin sensors and systems. Vehicular lifelogging is a specific context of use for lifelogging [1,11], where data about one's life events and experiences are stored for later retrieval, acting as an external digital memory support. According to Khan *et al.* [13], *"due to a bundle of sensors and other auxiliary devices, a vehicle or car can be intelligent enough to capture personal as well as car related data"* (p. 30). While there is a wide scientific literature on general-purpose lifelogging systems, considerably less attention has been dedicated to vehicular lifelogging. In this work, we rely on the principles of vehicular lifelogging to characterize digital content creation in connected cars. To this end, our main contribution is represented by a *design space for vehicular lifelogging*, which we use to characterize the features of prior systems and applications, but also to inform the design of a new prototype consisting of a smartphone and a pair of smartglasses with an embedded micro video camera. Next, we present a few motivating examples of vehicular lifelogging by showcasing practical uses of digital content creation in connected cars.

Examples and Use Cases for Vehicular LifeLogging

A few examples illustrate the opportunities of using vehicular lifelogging to create rich digital content in connected cars. We also use these examples to highlight design and engineering challenges, which we will later address with the dimensions of our design space for vehicular lifelogging.

- Martin commutes to work every day in his own car that features a state-of-the-art in-vehicle infotainment system (IVIS) including navigation, media player, and USB, Bluetooth, and Wi-Fi connectivity. Martin's smartphone connects to the IVIS to transfer phone calls and other content, such as text messages, which Martin considers to be an effective time saver to take care of various things while getting to work. As Martin is an efficiency enthusiast, he would like a detailed description of his journey to work in terms of car speed, fuel consumption, and time to destination, but also estimates regarding other activities, such as the time spent on phone calls and how taking phone calls in the car affects his driving performance. A custom vehicular lifelog focused on driving statistics correlated to mobile phone usage while in the car would help Martin to optimize his driving routine for better efficiency.
- John and Sarah are a young couple who enjoy taking vacations using their own car. They also enjoy taking photographs and video recording their life events. When back home, Sarah compiles digital memories of their holidays, using pictures, videos, and other digital memorabilia that were captured during the trip. For their new trip, John and Sarah purchased smartglasses with embedded video cameras. A custom vehicular lifelog would assist John and Sarah to recreate their visual experiences from snapshots of landscapes, cities, and other events from the road, automatically captured by their smartglasses and connected to the GPS locations of places they visited.
- The Johnsons use the family car each morning to get their two children to school. On the way to school, children use the rear seat entertainment system to take short quizzes about their homework. Parents believe that this activity helps children to use efficiently their time spent in the car. A custom vehicular log about children's performance regarding the various quizzes would serve parents, but also educators, to monitor children's learning progress outside the school environment.

These scenarios illustrate a variety of data that can be captured in connected cars. Some of these data are delivered by in-vehicle systems, such as driving statistics and GPS coordinates, others come from third-party services, while others are collected by mobile and wearable devices. This variety of data needs flexible software architecture to connect heterogeneous devices, applications, systems, and services [21] as well as support for engineering user interactions that are low effort and demand little to no cognitive effort [22] while driving. It also needs formal design knowledge about the type and nature of digital data that can be collected, and the formats to represent, store, and retrieve those data. Our space for digital content creation in connected cars mediated by vehicular lifelogging addresses such important aspects.

Contributions

In this paper, we adopt the principles of vehicular lifelogging as means to characterize creation and storage of digital content in relation to the connected car. The practical contributions of our work are as follows:

(1) We introduce a design space for vehicular lifelogging consisting of five dimensions: *nature*, *source*, *actors*, *locality*, and *representation*; see Figure 1 from the first page for a visual illustration. Our design space comes to fill an important gap in the literature, as *"a crucial aspect of lifelogging involves choosing what parameters to keep track of. This is essentially a question of what inputs matter and why. Novel lifelogging subjects (like cars) require innovative approaches to these questions"*; see [16, p. 229].
(2) We demonstrate the utility of our design space by characterizing the features of existing vehicular lifelogging systems and applications, but also by presenting a new prototype, informed by the dimensions of our design space, that employs a smartphone and a pair of smartglasses with an embedded micro video camera.

Our contributions fill in missing design and engineering aspects of an application area of lifelogging that has been little researched so far [13,14,16,24]. We hope that our design space will foster new research on vehicular lifelogging and inform new prototypes and applications for the creation, management, and sharing of digital content in relation to connected and hyper-connected cars.

2 RELATED WORK

LifeLogging has been described as a phenomenon, whereby people digitally record their daily lives [11], as personal big data [11], but also as a form of pervasive computing [10]. Notable examples of lifelogging devices from the scientific literature include SenseCam [12], the EyeTap technology [15], the DejaView system [8], or InSense [3], to name just a few. Also, several commercial products are now available for lifelogging enthusiasts, such as the Narrative Clip [18], MeCam [17], SnapCam [23], and Google Clips [6], among others.

Unlike the wide research available on general-purpose lifelogging, only a handful of prior work has addressed vehicular lifelogging [13,14,16,24]. For example, "Lytx Drive-Cam" [14] combines telematic sensor data and video recordings to help companies determine the causes for collisions involving the vehicles of their fleets, such as drowsy driving, distracted driving, speeding, following too closely, lane departure, or other driving behavior leading to accidents on the road. "Thea" [24] provide a smartphone application for day-to-day vehicle use that implements vehicle lifelogging and reports details about locations, routes, stops, mileage, fuel consumption, engine temperature, driving style, car accidents, break-in attempts, etc. Khan *et al.* [13] proposed a generic model for vehicular lifelogging consisting in ten items, as follows: (1) car life cycle, (2) traffic violations, (3) car assistance, (4) car statistics, (5) music and entertainment, (6) communication and social interaction, (7) car service, (8) traffic conditions, (9) location and navigation, and (10) weather information. Their goal was to identify technologies that could support vehicular lifelogging (*e.g.*, on-board diagnostic systems, GPS, in-vehicle infotainment systems, car cameras, and applications that connect to the in-vehicle systems), point to challenges for engineering systems for vehicular lifelogging, and formulate guidelines to foster new research and development on the topic.

McVeigh-Schultz *et al.* [16] discussed an automotive lifelogging system that leveraged in-vehicle sensors to engage drivers in discoveries about their vehicles, driving environment, and social context throughout the lifecycle of the car. The approach was centered on employing visual storytelling, theatrical experience design, and rapid prototyping to characterize the relationship between in-vehicle sensors and driving scenarios. Dobbins and Fairclough [9] employed vehicular lifelogging from the practical perspective of detecting the stress levels of drivers, to which end they proposed and evaluated algorithms to process streams of lifelog data, *i.e.*, heart rate, heart rate variability, and pulse transit time (computed from raw electrocardiogram and photoplethysmogram measurements) and driving data (vehicle speed, location, and first-person photographs of the environment). Their results revealed 86.9% accuracy for the detection of drivers' stress.

3 A DESIGN SPACE FOR DIGITAL CONTENT CREATION IN CONNECTED CARS

We present in this section our proposal for a design space for digital content creation in connected cars based on vehicular lifelogging [13,16]. Our design space focuses on *what* and *how* to lifelog, but also *from what perspective* experiences can be logged using in-vehicle technology and personal devices. We consider five dimensions to address the *nature* of the data that can be collected, its *representation*, modalities for *sensing*, *actors* that provide the perspective, and *locality* to characterize the spatial relationship between the vehicle and its occupants. We inspire from Khan *et al.*'s [13] generic model for vehicular lifelogging, including supporting technologies, but also from the five types of connectivity envisioned for connected cars [4], *i.e.*, vehicle to infrastructure (V2I), vehicle to vehicle (V2V), vehicle to cloud (V2C), vehicle to pedestrian (V2P), and vehicle to everything (V2X).

Nature of the data. Data collected in connected cars can have a wide diversity, from basic information about the vehicle (*e.g.*, model and make) to statistics about the journey (*e.g.*, fuel consumption and average speed [24]) and to user physiological data (*e.g.*, heart rate during driving as an indication of stress [9]). We identify the following design options, N_1 to N_5, for this dimension (also see Figure 2, top-left):

- N_1. *Vehicle-related* information, such as the car model and make, ownership, license plate, vehicle history, etc. The vehicle history can include various kinds of information, such as car accidents or break-in attempts [24].
- N_2. Data about *journeys*, such as travel speed, fuel consumption, locations traveled, routes to destinations, stops, etc.; see the Thea app [24] for smartphones.
- N_3. *Occupant-related* data that can vary from basic information (*e.g.*, how many occupants are in the vehicle) to more precise identification information (*e.g.*, who is in the car? who got off? [16]) and to logs of physiological data, such as the heart rate of the driver [9].
- N_4. The *in-vehicle environment*: data from the entertainment system (*e.g.*, the music played on the radio), an audio lifelog of the discussion of the occupants, etc.
- N_5. The *outside environment*: data about weather conditions, temperature, and traffic.

Sources of data. A variety of systems and services support creation of content in connected cars (Figure 2, top-right):

- S_1. *Built-in* sensors and systems, such as the on-board diagnostic system [24] and video cameras [14].
- S_2. *Mobile devices*, such as smartphones and tablets, operated by the occupants of the vehicle [24].
- S_3. *Wearable devices*, such as smartwatches, smartglasses, and wearable video cameras worn by the occupants.

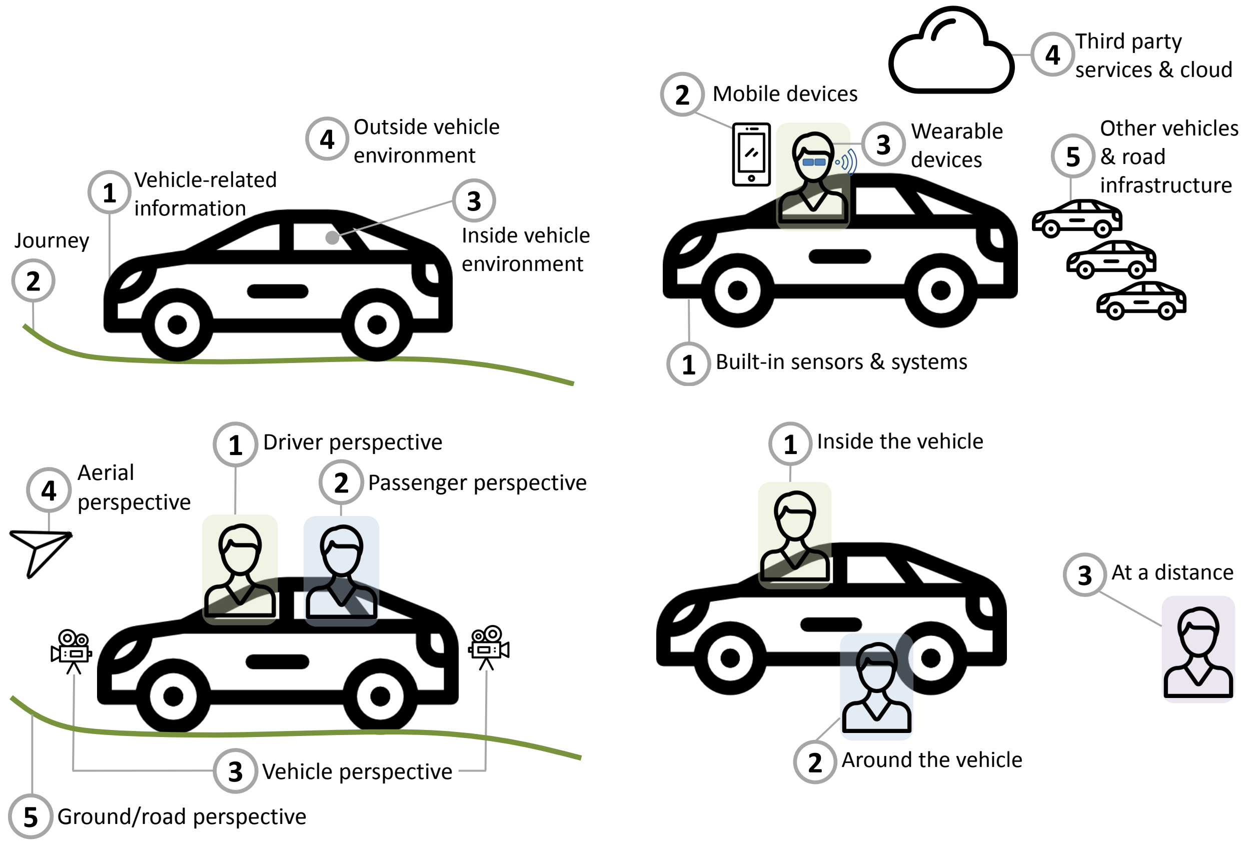

Figure 2. Visual illustrations of the *nature* (top-left), *sources* (top-right), *actors* (bottom-left), and *locality* dimensions.

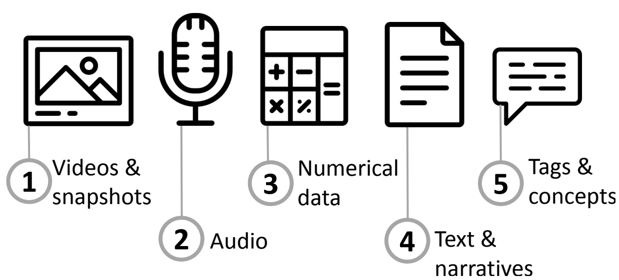

Figure 3. Visual illustration of the *representation* dimension of our design space. Continued from Figure 2.

S_4. *Third party systems and services*, such as real-time information about the weather and traffic [25] and feeds from social networks.

S_5. *Other vehicles* passing by can deliver other types of information, such as regarding particular traffic conditions not available to the navigation system.

Actors. The in-vehicle environment offers the opportunity of multiple perspectives for logging vehicular content. According to McVeigh-Schultz *et al.* [16], *"a car has a single lifelog, but multiple drivers can contribute to that lifelog independently"* (p. 227). Correspondingly, we identify the following options for the *Actors* dimension (Figure 2, bottom-left):

A_1. *Driver*'s perspective, captured by wearable video cameras and cameras embedded in smartglasses.

A_2. *Passengers'* perspective, captured by wearable video cameras and cameras embedded in smartglasses.

A_3. *Vehicle* perspective, from built-in video cameras [14].

A_4. *Aerial* perspective, captured by drones [7].

A_5. *Ground road* perspective, delivered by traffic surveillance systems [2].

Locality. Vehicular data logging can take place when the occupants are inside, but also outside the vehicle. We distinguish the following options (see Figure 2, bottom-right):

L_1. *Inside* the vehicle: data is captured from sources S_1-S_5.

L_2. *Around* the vehicle: data is captured mostly using mobile (S_2) and wearable (S_3) devices.

L_3. *At a distance* from the vehicle: sources S_4 and S_5.

Representation. Data can be stored in various representations, from snapshots to concepts and tags automatically extracted from those snapshots (see Figure 3):

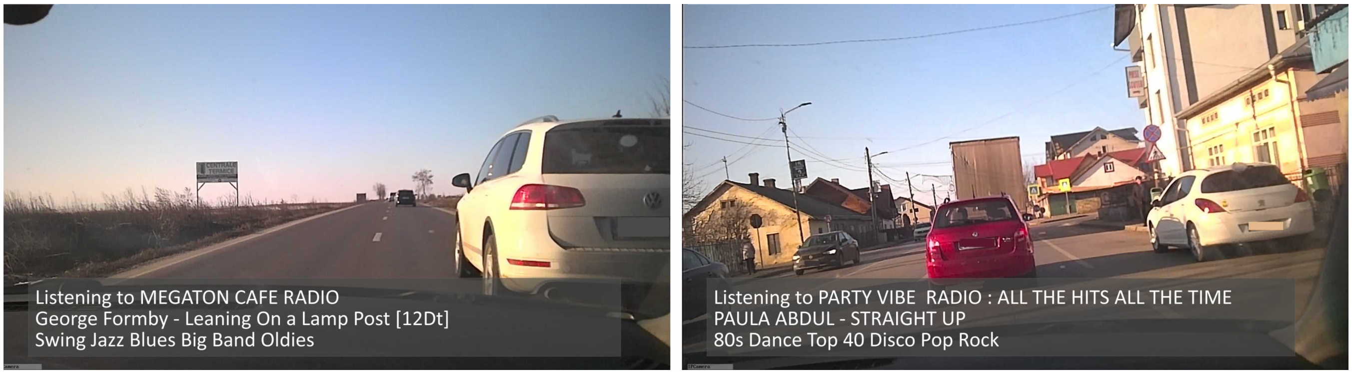

Figure 4. Examples of two snapshots captured from the passenger's perspective (A_2) with our prototype for smartglasses (S_3) and smartphone (S_2). Superimposed the snapshots are the metadata from the online radio stream (N_4).

- R_1. *Videos & snapshots* captured by built-in video cameras and cameras worn by the occupants [11,26].
- R_2. *Audio logs*, for example of the discussion taking place among the occupants of the vehicle.
- R_3. *Numerical data* delivered by various sensors, such as speed logs [24] or the heart rate of the driver [9].
- R_4. *Text data* represented by details regarding the content played on the radio or by the in-vehicle infotainment system, or a summarizing narrative of the lifelog [20].
- R_5. *Tags & concepts* automatically extracted from snapshots captured by a video camera [1], which can be built-in or worn by the driver or the other occupants.

4 PROTOTYPE

We demonstrate our design space by using it to characterize previous vehicular lifelogging systems and applications [14, 16,24] and by showing how it can inform new prototypes.

Figure 1 from the first page illustrates the five dimensions of our design space, where we represent vehicular lifelogging systems from the scientific literature [16] and actual products [14,24]. For example, McVeigh-Schultz *et al.* [16] described three application scenarios for vehicular lifelogging: car wash, "LA Dystopia," and recognizing social context [16] (pp. 228-229). In the car wash scenario, built-in rain sensors (S_1) capture information about the outside environment (N_5), which is a numerical format (R_3) representing the vehicle perspective (A_3 and L_1). Therefore, this scenario can be described as $N_5 \times S_1 \times A_3 \times L_1 \times R_3$ using the five dimensions of our design space; see Figure 1 for a visual representation. The other scenarios can be represented in a similar manner.

We can also use the dimensions of our design space to inform new systems and applications for vehicular lifelogging. To this end, we designed and implemented a new prototype with the following components, features, and functionality:

(1) Smartglasses (S_3) capture snapshots (R_1) of the visual reality experienced by the passenger (A_2) located in the front seat of the car (L_1). We employed the SS-IP13 glasses[1] featuring an embedded micro video camera and a wireless connection that can be used to stream video to any client performing requests over HTTP.
(2) An Android application running on the passenger's smartphone (S_2) uses the built-in GPS sensor to log the journey (N_2), the speed of the car [5] (N_1), and the music played during the journey (N_4) implemented with online radio streaming, from which metadata is extracted regarding the radio channel and the title and the genre of the stream.[2]

Figure 4 presents two snapshots captured from the passenger's perspective, *i.e.*, the $S_3 \times A_2$ design combination. Regarding the data representation dimension, our application stores snapshots (R_1) captured by the smartglasses, numerical speed measurements (R_3) estimated by the GPS embedded in the smartphone, and text descriptions (R_4) of the music played on the online radio channels streaming to the smartphone, *i.e.*, $R_{[1,3,4]}$. Overall, our prototype design can be characterized in terms of the five dimensions of our design space as $N_{[1,2,4]} \times S_{[2,3]} \times A_2 \times L_1 \times R_{[1,3,4]}$.

5 CONCLUSION AND FUTURE WORK

We introduced a design space for digital content creation in connected cars, which we discussed by adopting the perspective of vehicular lifelogging. The goal of our design space is to systematize knowledge in terms of the type of digital data available to connected cars to foster new research and development regarding smart applications that create, store, and share data about vehicles, drivers, occupants, and journeys. For example, our design space shows that some

[1] SS-IP13 is a local vendor name for the smartglasses spy camera produced by NorthVision Technologies, http://northvisiontec.com/products/camera-spy/glasses-eyewear-camera/nc-c05glasses-camera19201080-avi-tf-card-videophoto-876.html
[2] The Android Arsenal - Audio - audiostream-metadata-retriever, https://android-arsenal.com/details/1/1774

dimensions have been little explored in prior work, such as *Source* or *Actors*, suggesting future work in this direction. Other future work regard interaction techniques to visualize and manipulate digital content in connected cars, inside and outside the vehicle, as well as new applications for mobile and wearable devices that use the data collected in connected cars to improve the drivers' and passengers' experience of the journey.

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