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Engineering, Human, and Legal Challenges of Navigation Systems for Personal Mobility

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***Abstract*—Walking is now promoted as an alternative transport mode to polluting cars and as a successful means to improve health and longevity. Intelligent transport systems navigation services are now directly targeting travelers due to smartphones and their embedded sensors. However, after a decade of research, no universal personal navigation system has been successfully introduced and adopted to improve personal mobility. An analysis of the underlying reasons is conducted, looking at the engineering, human, ethical, and legal challenges. First, contrary to adopting classical mechanization equations linked to solid state physics, location technologies must address complex personal dynamics using connected objects. Second, human factors are often not sufficiently considered while designing new technologies. The needs and abilities of travelers are not systematically addressed from a user-centered perspective. Finally, people want to benefit from location-based services without sharing personal location data to uncontrolled third bodies. Europe is a pioneer in the protection of individuals from personal identification through data processing since location data has been recognized as personal data, but the challenges to enforce the regulation are numerous. The recommendation of "privacy by design and default" is an interesting key to conceive the universal personal navigation solution. Alternative solutions are highlighted, but they definitively require a more interdisciplinary conception.**

***Index Terms*—Pedestrian navigation, positioning technologies, Design challenges, personal data privacy, navigation.**

I. Introduction

OUR World has been shaped by human displacements over millennia. Waves of immigration followed the navigation of explorers in unknown territories. The development of faster transport means introduced new opportunities for traveling farther in shorter time periods. The technology evolved for assisting the navigation of various vehicles: ships, trains, airplanes and private cars. With the advent of smartphones and their embedded sensors, providing new navigation functionalities, navigation services are now directly targeting humans carrying mobile devices instead of the vehicles that transport them. Another consequence of this evolution is that the environment, where navigation technology is expected to be working, has extended to challenging indoor spaces and to the context of human walk. Positioning and navigation solutions must address the mobility and the dynamic of pedestrians with connected objects instead of adopting mechanization equations linked to solid state physics.

At the core of this new paradigm are on-foot travelers within Intelligent Transport Systems. Today, people want to benefit from location-based services (LBS) without sharing personal location data to uncontrolled third bodies. In the future, they will be willing to improve their personal mobility with an increasing part of active transport for improving their health and reducing their living costs. The pedestrian of tomorrow shall also enjoy new experiences thanks to real time positioning and navigation data for discovering the World and contributing to its evolution at its individual level with its own creativity. We have entered the new era of mass customization.

The growth of digital applications and the associated massive data collected daily enable the construction of a digital profile for each person. This new option for characterizing human beings contributes to the development of customized mass market services. The inherited difficulty is that understanding the construction of digital profile and managing it with existing tools is an almost impossible task. It is both a tools and a constitutional problem. However these actions are very important for the society since digital profile addresses every person directly and individually. Globally this artificial identity can be foreseen as the concentration of all prints registered during the "online life". Among these prints are the geographical positions collected along personal journey. They constitute a fundamental element of the later and are the subject of personal data protection debates. It can be stated that more and more personal positioning and navigation systems are developed but none of them is adopted as a universal solution. Whereas a large variety of technological solutions is specifically designed for pedestrian navigation applications, they are not providing continuous, autonomous and accurate dynamic positioning without threat inherent to uncontrolled recorded personal tracks. Integrating the human dimension in positioning and navigation solutions requires a breakthrough approach that has not yet been completely followed.

Despite more than a decade of research and development, no universal personal navigation system has been successfully introduced and adopted. Analyzing the possible reasons from

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different perspectives is at the core of this inter-disciplinary position article. Indeed, it is proposed to investigate this statement from three points of view:

- the engineering challenges,
- the human challenges, and
- the ethical and legal challenges.

II. Engineering Challenges

A. The Surveyors and GPS Heritage

Navigation science has enabled the human to explore, map and understand the World for centuries. In the Stone Age, natural landmarks were used by early man for finding their way. With the advent of surveying instruments, navigators discovered the World using celestial navigation. According to Gavin Menzies [1], Chinese Admiral Zheng He's fleets had already circumnavigated the globe in the 15th century, before the expedition of Ferdinand Magellan. Finding its geographical position based on observations to surrounding "reference points" was the first real solution to the location problem. In the 20th century, scientists discovered new ways for measuring distances using the propagation time of radio signals between a transmitter and a receiver. This principle is at the origin of the American Global Positioning System (GPS) where the "reference points" became Earth orbiting satellites. In the same century, dead-reckoning navigation was invented. Unlike previous solutions, this method tracks position and orientation of a body relative to a known starting location using only self-contained inertial measurements. Next step was to combine trilateration and strap-down dead-reckoning processes for accurately assisting transport applications. The evolution of navigational science followed a logical sequence based on the assumption that instruments are directly sensing the motion of the tracked body. With the new paradigm of personal navigation with handheld smartphones, this assumption no longer holds. But why is the pedestrian a special case for the development of positioning and navigation algorithms?

B. The Features of Pedestrian Navigation Algorithms

Pedestrian navigation differs widely from the navigation of motorized bodies in many aspects. A comparison of these two elements leads to the definition of features that can be used to characterize the specificities necessary to design navigation algorithms for personal mobility. These features are illustrated in Fig. 1 and detailed in the following paragraphs. Let us state that globally any solution developed for pedestrian positioning and navigation application should address these features even if it is not necessarily the case nowadays and is a very challenging task.

1) Freedom of Movements: Technologies developed for positioning and navigation are not error free. To counter this difficulty, map information is commonly used to constrain the position of a mobile object on the most probable position estimate. For example, the statement that cars drive on road networks can be used to reduce the set of probable cars' positions. If a route has been planned based on origin and destination data, it can also be used for mitigating positioning errors. Bayesian and sequential Monte Carlo based methods are classically used to apply map constrains. Their performance depends on the availability of geographical data to constrain the dynamic of the mobile object. What can be the map constrains for pedestrian mobility? Answering this question shows why the first feature of pedestrians during their travel is to be free.

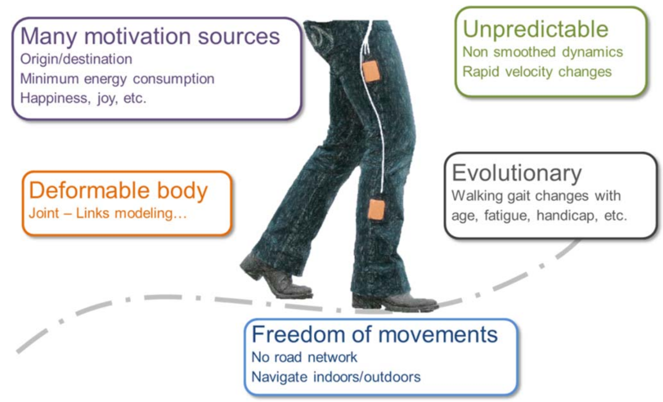

Fig. 1. Design features of pedestrian navigation algorithms.

By definition, pedestrians have a large freedom of movements in their displacements. They can travel through 3D spaces in any directions, in indoor/outdoor spaces and decide not to follow what urban planners have designed for their security (crosswalk, sidewalk, etc.) or their comfort (paved road in green spaces). Inside buildings, obstacles can be identified and used to constrain the motions of particles representing the possible traveler's locations using particles filtering techniques [2]. Constrains are walls, staircases, lift or furniture limiting possible movements. Translating these obstacles into navigation routes is however very complex. Some approaches extract principal directions from a building to define preferred routes, but pedestrians can choose not to follow them. This is for example the case to avoid a person coming in the opposition direction. In this situation the obstacles are moving and not described by map data. The use of virtual tracks is also proposed to keep a higher degree of freedom in environments that have already been mapped by joint and link models [3]. Not only is the choice of preferred trajectories questionable, but its definition becomes even more complex in large spaces (exhibition hall) that can be crossed in any direction. Other research proposes to build routes based on the observation of large amount of pedestrians' tracks following a machine learning process [4]. This strategy is supported by the facilitated access to big data and crowdsourced information, but the quality and reliability of these data can be questioned and is often difficult to assess. Irrespective of the chosen approach, the large degree of freedom in movements is a specific feature of personal mobility that adds complexity to the conception of a universal navigation solution.

2) Many Motivation Sources: Contrary to the majority of the navigation systems onboard vehicles, the computation of on-foot navigation routes is not only motivated by the fastest or shortest route between the origin and destination locations. Although optimizing these features remains the primary choice for routes estimation, other motivations exist. Among them

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are the search for the minimum energy consumption and the emotional experience. Naturally, pedestrians aim at minimizing the energy spent in transport and adopt economical walking speed. Finding the routes associated to the minimum energy expenditure is natural to humans but it involves cognitive abilities that are not easily duplicated by artificial intelligence. Consequently a universal pedestrian navigation solution should be able to assist personal mobility without constantly using human navigation senses (e.g. vision focused on the mobile screen). Experiments have shown that energy consumption is linked to the walking speed, the ground slope, its nature but also physiological parameters. In the recent study of Virtanen [5] energy expenditure is applied to the problem of pedestrian routes finding. The algorithm is based on the hiking function [6]: a velocity over slope ratio that eliminates the dependency to physiological factors such as the weight. This work illustrates alternative approaches to the shortest route finding strategy. It depends on the availability of a 3D geographical information system containing the navigation routes of on-foot traveler, which is often incomplete. Globally the design of routing algorithms for personal mobility must consider new dimensions that are specific to pedestrians as compared to existing vehicles routing algorithms.

3) Deformable Body: Historically, geographical positioning systems consider that the measurement point corresponds to both the location and the dynamics of the mobile object. Sometimes, the position of the measurement point (GPS or WiFi antenna) is transposed to the position of interest (the vehicle center of gravity CoG) using the known rigid lever arm between the two positions. In this case, it is possible to apply the physics of solid for estimating the Cartesian position transpose. When the positioning device is held in hand the situation is completely different.

Indeed, the lever arm between the handheld device and the traveler's CoG keeps changing depending on the global locomotion and the activity of the upper part of the human body. For example, while phoning the location of the device is close to the ear, but while walking with freely oscillating arms, the device will go cyclically in front and behind the CoG. This movement corresponds to an averaged error of 30–40 centimeter as compared to the position of the CoG and corresponds already to a 50–60% error over a 60–70 centimeter mean step length. These lengths correspond to an average healthy young adult [7]. Of course, these quantities vary a lot depending on the nature of persons but the percentages remain in the same order of magnitude. Cumulated over several steps, this error will definitively lead the traveler to the wrong destination. In the context of pedestrian positioning and navigation, the lever arm can be qualified as "deformable", making it more difficult to develop efficient navigation solutions and systems.

Since the introduction of Kalman Filter [8], estimating the navigation solution (Position, Velocity and Time) of a mobile body is not solely based on the processing of measurements (Time of Flight, Angles of Arrival, etc.) but also on time-propagation knowledge of the navigation state. For example, the position estimate of a car is predicted forward using the velocity estimate whose time evolution is described by the dynamics of the vehicle. Being able to describe the dynamics of mobile objects becomes critical for achieving good positioning performances. When pedestrians are using smartphones or wristbands, the hand's dynamics does not correspond to the global motion of the pedestrian and the relation between the time-evolution of the navigation solution and the pedestrian is not direct. This complexity is even greater when the positioning algorithms try to process inertial signals (accelerations, angular rates) sensed by the handheld device to estimate walking directions. The reason is that the traveler's walking direction is different from the handheld device pointing direction leading to a continuously changing angular misalignment. This observation further illustrates the "deformable nature" of human body in designing universal pedestrian positioning and navigation solutions.

4) Evolutionary and Unpredictable: Human walking gait is defined by cyclic periods of stance and swing phases of both feet [7]. During the stance phase, the foot is in contact with the ground. This period starts with a heel strike, ends with a toe off and corresponds to 60% of the gait cycle. During the swing phase, the same foot is in the air. This phase completes the remaining 40% of the gait cycle for the same foot. The cyclic nature of human gait being very interesting, many pedestrian navigation algorithms are trying to use biomechanical information to improve the accuracy of the estimated locations of the traveler. For example, step length models have been developed to estimate the distance traveled by pedestrians [9], [10]. Combined with walking direction estimates, it is possible to describe pedestrian tracks by a series of locations corresponding to the steps. This approach corresponds to the pedestrian dead-reckoning (PDR) mechanization strategy that propagates position of the traveler based on the previous one. The performance of PDR strongly depends on the validity of the models involved in the location processing and personal physiological parameters. Consequently these models must be calibrated for each traveler since walking gait patterns are different for every individual. Indeed, a healthy young adult will not walk in the same manner as an elderly person. In fact, the evolutionary nature of human gait is not only true for different persons at different ages but also for the same person depending on his/her state of fatigue or simply the weight of a carried bag [11]. Individual and regular calibrations of PDR models appear to be necessary and might be complex when the design of a universal navigation solution is at stake. Globally the complexity of human gait questions existing location estimation approaches. Indeed, pedestrians are moving in "non-smoothed" manners that are difficult to model. They can abruptly stop their walk, start to run to catch a bus or quickly turn to respond to a friend. As such, daily travels can be qualified as unpredictable.

C. Existing Technologies: Infrastructure Based and Infrastructure Free Solutions

Fig. 2 summarizes the performances of existing technologies in terms of positioning accuracy and coverage. Two categories of technologies exit:

- terrestrial infrastructure based and
- terrestrial infrastructure free technologies.

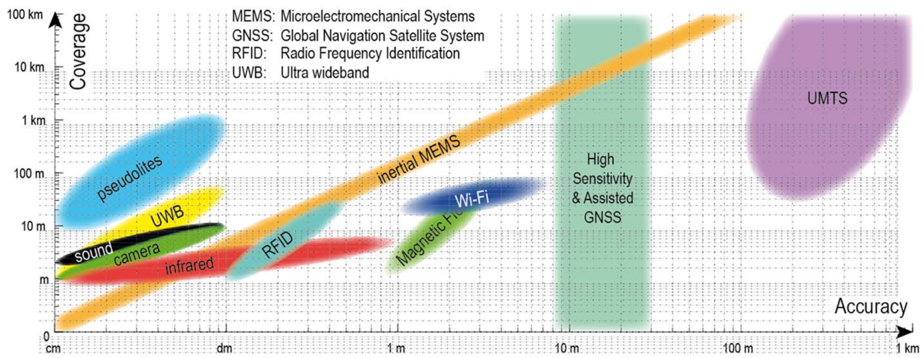

Fig. 2. Performances of positioning technologies as a function of accuracy and coverage.

The first category: involves specific or densified network of terrestrial beacons whose data are processed for estimating the position of mobile objects. They fall into the “terrestrial infrastructure based” category. Their development has been pushed by the bad performances of existing navigation solutions in indoor environment, especially GPS since satellites signals are strongly deteriorated and cannot easily be tracked inside buildings. The propagation of radio signals from terrestrial networks is modeled to measure either distances using time of arrival (TOA) or time difference of arrival (TDOA), or bearings using angle of arrival (AOA). The positioning principle is either based on trilateration (ranging to known points) or triangulation (intersection of vectors described by an angle and an origin). Main difficulty is that indoor/urban spaces are full of obstacles that perturb the propagation of radio signals and deteriorate the positioning accuracy. Globally, their performance level is linked to a costly balance between accuracy and base stations’ density. Fingerprinting is another approach that has been adopted as the most common localization principle. It relies mainly on received signals strength indicators (RSSI) that are compared with a-priori radio propagation maps for extracting pedestrians’ location. The same RSSI mapping principle was also recently applied to magnetic anomalies [12] or ambient radio frequency (RF) signals. Without specific update, this principle assumes that the RSSI are constants in a mapped environment. This assumption is often wrong for personal mobility services because the traversed spaces are not stationary in terms of signal propagation and human locomotion often happens in crowd where the human tissues absorb RF signal energy at higher frequencies. The consequence is that impractical continuous updates are required to guarantee reliable and accurate position estimates.

The “terrestrial infrastructure free” category includes sensors whose data are recorded and processed without using a radio link to a local terrestrial IT server/network. The most common example of terrestrial infrastructure free technologies is GPS since the satellites are continuously broadcasting signals over the earth and the receiver works in a standalone mode to estimate its location. GPS is a “privacy by design” positioning technology based on trilateration. This method is efficient for positioning outdoors with Global Navigation Satellites Systems (GNSS) signals [13], but it cannot easily be applied in urban or indoor surroundings where the signals suffer from strong attenuation, fading and multipath effects. Satellites signals reaching the Earth can be 50 dB weaker than the ambient noise. In the same category, vision-based methods have also been proposed. Primary developed for 3D mapping, they are now proposed to navigate based on SLAM or visual odometry processing strategy [14]. They suffer from brightness variations, from the availability of features’ disparity in the scene and often force the user to walk with his eyes looking at the screen (unrealistic and dangerous motion). Recently it has been proposed to use magnetic fields, even perturbed by man-made sources, to navigate. Instead of using an “e-compass” approach, where the azimuth is derived from the earth magnetic field, magnetic field gradients are filtered to directly estimate the velocity [15] or the angular rates [16]. Finally, self-contained inertial microelectro-mechanical systems are proposed. They show a different performance signature in Fig. 2 (orange). There is no coverage limitation but the performance deteriorates with the propagation of sensors errors.

More recently, big data strategies are adopted for addressing existing technological failures. Crowd sourcing information or decentralized computing centers are exploited for deriving aggregated displacement data of smartphones users based on uniform models with the threat inherent to uncontrolled recorded personal tracks.

D. A Trend: Capturing Human Locomotion With Handheld Sensors

With more than one billion of smartphones sold worldwide in 2013, this device holds a privileged position in people’s daily lives. It can even be seen as a smart extension of human arm. Navigational science has not yet fully considered this evolution for inventing novel processes, but understanding the coordination between the arm/hand and global locomotion sensed with embedded low-cost multiple sensors is very promising for providing continuous, autonomous and accurate dynamic positioning of pedestrian. What if pedestrian human gait features could be accurately sensed with handheld units and even used to compensate for the error propagation of low cost sensor errors?

The objective of navigation algorithms is to estimate a series of triplets: Position, Velocity and Attitude angles (PVA) that defines the walking path. The state of interest is the average walking speed vector, but with signals recorded in hand, existing navigational filters are tracking the hand’s motion instead. In the context of pedestrian navigation, this approximation may be accepted if the estimated location accuracy, integrity and robustness meet urban and indoor positioning requirements: 1 m accuracy with percentile 95% [17]. However, numerous errors accumulate, producing large positioning inaccuracy. The perturbation sources are manifold. A non-exhaustive list is: the low quality of Micro Electro Mechanical Systems (MEMS) based inertial sensors, fading, shadowing and multipath effects of urban environments on radio signals propagation and the chaotic nature of human motion, dynamic lever arm.

Ongoing research aims at solving these issues by extending existing navigational science methods to the context of pedestrian navigation [18], [19] but a new scientific framework seems inevitable for having a profound impact on the performances of pedestrian navigation algorithms. Understanding and modeling the diversity of human gait is at the core of this research.

III. Human Challenges

A. Human-Centered Design

The rapid development of new technologies has produced many new mobile systems that are deployed without systematically considering pedestrians' needs and abilities in their design. Moreover, these new systems have not been systematically evaluated from a user-centered perspective before being placed on the market [20]. Even if human factors are of great importance for the design and introduction of new mobile technologies, they are often not considered in sufficient details.

A mobile service system must satisfy requirements linked to the user, his/her context and the service concept. The two last requirements are generally satisfied by engineers while designing the technology, but the first ones not so much. General human factors such as the perceptual, cognitive, and motor abilities that are necessary to perform the tasks the technology has been designed for, must be taken into account (and de facto, the limited capacities of human beings). These human characteristics influence the way individuals will interpret, decide, act and use the technology. Specific and unique characteristics of the intended user population must also be addressed, such as their education level, their knowledge and skills, and their prior experience [21].

From a human-centered perspective, the quality of a new system can be defined by its utility, usability and acceptability. Utility means relevance or efficacy. It allows the user to reach his/her goal and can be evaluated by objective measures linked to performance on the tasks the system is designed to support [22].

Usability refers to the ease of use. It is a concept widely used in ergonomic studies when talking about technological design and quality of interactive systems (e.g. [23]). Usability is actually one of the most important pre-condition for the acceptability of the system, the two concepts being the leading criteria for the success of the technological design, beyond its utility. There are several definitions of usability. The international standard ISO 9241-1 defines usability as the extent to which a product can be used by specific users to achieve specific goals with effectiveness, efficiency and satisfaction in a specific context of use (ISO 1997). But a high level of usability doesn't necessarily mean that users will adopt the new technology, buy it and use it in their daily life.

User acceptance is described by "the demonstrable willingness within a user group to employ the technology for the tasks it is designed to support" [24]. Lack of user acceptance is actually an impediment to the success of newly implemented technologies [25].

For many years, professionals of human factors and ergonomics have been interested in identifying and understanding the determinants of use, utility, usability and user acceptability of novel technology in order to support engineers, minimize resistance and maximize the adoption [24]. In this line, the acceptance of new technologies is investigated by many researchers and practitioners since the 1990s [26]. The original meaning of the acceptance of a new technology could simply relate the use of that technology to the user: if it is acceptable to people, they will use it. But the determinants of acceptance are more complex than the use and usability of the system because they also depend on external elements such as, the characteristics of the individuals using the technology, the context in which it is implemented, the advantages over other available tools and the compatibility with existing social norms and practices.

The research on technology acceptance aims at explaining and predicting the perception and adoption by the end-users of new technologies. Famous technology acceptance theories, such as the Davis's (1989) Technology Acceptance Model (TAM) [27], primarily focuses on job-related usage of information and communication technologies. Nevertheless this model has also been used and studied in several other contexts. Among them are navigation tasks of general users and car drivers.

TAM's goal is to predict users' acceptance of a technological tool and diagnose design problems before the users acquire significant experience with the system. According to Davis [27], user's acceptance is influenced by two key factors: the perceived usefulness (i.e. the degree to which a user believes that using the system will enhance his/her performance) and the perceived ease of use (i.e. the degree to which the user believes that using the system will be free from effort). These two concepts determine attitudes toward using the system and influence the decisions of individuals for using a particular technological tool, i.e. the behavioral intentions to use it, which in turn determines the actual use of the system. Perceived usefulness and perceived ease of use are influenced by individual differences, system characteristics or social influences. Theoretical extensions of the TAM have been published, the third version TAM 3 [28] being the most recent one. In addition to the TAM models, specific scales have been developed to measure perceived usefulness, perceived ease of use and attitudes toward using and behavioral intentions to use. These scales have been validated in several studies and allow both industrial and academic fields to evaluate new technology with a practical and cost-effective method and predict the degree to which end-users will use that technology before the system is actually implemented.

In contrast to the well-studied car navigation context [29], less studies have used such conceptual frameworks to study how well individuals may adopt outdoor and/or indoor pedestrian navigation systems. Although an automobile market and the related industrial players exist for many years, there is no "pedestrian/traveler" market yet. While new navigational services have emerged on mobile devices over the last few years (e.g. Google maps), these services were initially designed for in-car navigation and are not necessarily suited to the pedestrians' needs [30], [31]. Published studies about pedestrian navigation aids mostly focus on evaluating general usability, satisfaction and ease of use. Usability is either evaluated by the system developers or by bringing the users into contact with the product [32]. A recent survey of existing assessment methods highlights an increasing number of usability evaluations conducted in natural research settings, i.e. field studies [33]. Laboratory tests are also very useful for testing the usability of mobile applications [34]. But there is still a gap in research that really embraces the full extend and complexity of the real world in which the mobile systems are used [33]. Moreover, utility, usability and acceptability of navigation systems are not systematically and empirically evaluated among various groups of users, such as young and older ones, and by adopting a longitudinal methodology, to highlight changes over time. Finally, usability engineering is not systematically included in the roadmap of companies developing new personal services [20].

B. Outdoor Navigation Systems

Online map display based services provided by mobile devices such as smartphones are one of the most widely and frequently used technologies. Usability studies, such as the ones conducted in [20], [32], evaluate context-aware online map-based services on mobile devices. They provide better understanding of the users' behavior, their tasks and their environments. Their results could be directly used in the product design following a user-centered design cycle. Such studies are commonly made with quite small user groups (e.g. 6 test persons between 24–60 years in the study of Nivala and Sarjakoski [20]). Beyond usability studies and a large part of research dealing with the design of usable mobile map-based interfaces [35], only few studies have targeted users' acceptance of these map-based mobile services, as well as their attitudes and intentions over time, even if these two last factors are considered keys to a successful implementation of such new technologies. The study of Park and Ohm [36] recently employed the TAM model and focused on the perceived usefulness of mobile map-based services through interviews with user and expert groups and thanks to a large online web survey with 1109 participants. Users appeared to be more affected by usability factors relating to interface experiences (e.g. service quality) than by technical factors (e.g., perceived locational accuracy). Four factors seem to particularly influence users' perceptions and attitudes towards mobile map-based services: satisfaction, perceived location accuracy, service and display quality, as well as the feedback given by the device about personal mobility. Flow state was also shown to play a significant role: i.e. the user's feeling of immersion in the mobile environment, his/her feeling of being in the virtual space. A factor that this study did not consider is the age of the users, whereas individual characteristics may have notable effects on attitudes toward services provided by geographic information systems. Most of published studies concentrate their efforts on young users, although old people could also largely benefit from navigation tools available on mobile devices. This question was studied by Riebeck *et al.* [37] who showed that mobile information systems are also of interest for elderly users when navigating unfamiliar environments (tourism) despite their lack of experience in mobile computing technologies.

If map-based navigation applications on mobile phones can be useful, they have downsides such as their small screen size. Moreover, users have to associate the information provided by the mobile phone with the real surrounding world. To overcome these issues, an alternative [38] was proposed to provide navigation information using public displays. The developed Rotating Compass comprises a floor display that continuously shows different directions (in a clockwise order) and a mobile phone that informs users when their desired direction is indicated (vibrations synchronized with the indicated direction). The outdoor study compares a conventional paper map, a navigation application running on a mobile phone, navigation information provided only by a public display and the Rotating Compass (combination of both public display and mobile phone information). Twelve participants took part in the study. The results showed clear evidence of the advantages of the new interaction technique when considering the task completion time, context switches, disorientation events, usability satisfaction, workload and multi-user support.

Heinroth and Bühler [39] assessed also the usefulness, ease of use, convenience and willingness to use outdoor pedestrian navigation system that guides users with the help of spoken landmark-based directions to their destination. Actual mobile map-based services on smartphones often require the use of vision, which is however a sense already solicited when walking, thereby triggering potential interference effects. A common strategy used by pedestrians when navigating in unfamiliar environments is indeed to directly ask other people for the way. Being accompanied by a human local guide would be optimal, but this is not always possible. A permanent virtual local guide is proposed by the speech-based pedestrian navigation system prototype developed by Heinroth and Bühler [39]. This Personal Device Assistant comprises a portable terminal, a Bluetooth-connected mobile phone providing Internet connectivity and a GPS receiver estimating current pedestrian's position. To provide enough bandwidth for the voice transfer via Skype, the mobile phone must be connected to an UMTS network. The prototype was evaluated by 18 subjects in predefined test area in a German suburb following a specific route. Findings yield insights about the usefulness, the usability and the user's acceptance of a navigation system that guides users nearly without the necessity of using a visual display but with the help of spoken, landmark-based directions. The landmark-enriched directions were rated very positively. Controlling the system by the use of spoken commands was found to be also very comfortable for the subjects. Almost all users (95%) were able to correctly complete the navigation task with the help of the speech-based system. But caution should be taken when designing navigation aids only based on verbal instructions [40]. Providing detailed contextual information is a challenging task and in noisy environments, verbal information is sometimes inaudible. Age-related sensorial decrements should also

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be considered. If such a system relieves free vision from the main task of navigating in familiar or unfamiliar environments, it requires audition that is also used when walking. Such a navigation system could therefore distract individuals from safe engagement in potentially hazardous environments. Audio based navigation system might introduce potential interference and have counterproductive effects, e.g. isolate the user from ambient noises.

Overall, the development of outdoor navigation systems over the last recent years tends to explore various technical means and different sensory channels to guide pedestrians. Further efforts are required for achieving solutions whose design is effectively more human-centered, including the diversity of uses and users and with increased and robust localization accuracy. Beyond promoting a more efficient personal mobility (e.g. by guiding through the shortest distance), the aim of these systems should also be to help improve on foot traveler's security, by proposing safer roads where no roundabout or multi-lanes street should be crossed and by guiding pedestrians to the nearest pedestrian crossings for example. Successfully mixing mobility and security is a major goal that must quickly be addressed if our societies continue to promote walking and active transport as an alternative mode of transport to polluting cars.

C. *Indoor Navigation Systems*

While outdoor navigation is already widely used in the context of car driving and comforted by rapid progresses for pedestrians, the development and usage of large public indoor navigation devices is still in its infancy [41]. In line with the rapid developments of localization technologies, mobile devices, display technologies and data transfer rate, the interest in new systems to help pedestrians navigate in indoor environments has considerably increased [42]. Indoor navigation systems can assist a wide range of activities, such as tourism, to support travelers in finding sights and points of interest inside buildings, monuments or shopping malls, but also for safety and health applications guiding lost patients in care services or providing individual navigation aid to people with specific needs (e.g. physical or visual impairments).

Similarly to outdoor navigation, the majority of indoor mobile navigation tools visualize route information on a mobile screen. For example, Serra *et al.* [43] developed an indoor pedestrian navigation system based on the dead reckoning positioning method, which process data from accelerometers and magnetometers available in common smartphones, and 2D barcodes. They conducted experiments in a real indoor environment and measured the encountered errors but did not evaluate the usability and acceptability of the device by the end-users themselves.

More recently, progresses in miniaturization (e.g., small cameras and projectors) lead to the introduction of compact mobile projectors into the market with a high application potential in the context of pedestrian navigation. Combined with indoor localization technologies, projector-based navigation systems enrich the real environment with route information, orientation instructions, point of interest, etc. that are projected on the floor. Compared with mobile screen-based navigation interfaces, the projector directly projects the navigation instructions into the user's environment, removing the need to switch attention between the screen and the real world. Moreover, instead of displaying information on a small screen, projectors can enlarge the content.

Li *et al.* [41] recently evaluated the effectiveness of a mobile projector-based navigation aid. They compared different navigation devices (mobile projector vs. mobile screen) and several ways to present navigation information (map vs. arrow) and also studied the impact of users' cognitive spatial abilities. Results showed the superiority of the mobile screen used as a navigation aid and the map as a navigation information type. Users with low cognitive spatial abilities benefited particularly from this combination at both levels: navigation performance and device acceptance. The low utility of the projector as a navigation aid was actually perceived by users themselves; they reported a higher workload when using the projector as compared with the mobile screen navigation aid. The mobile screen was clearly preferred over the projector. Privacy concerns were also shown to be an important barrier to the projector acceptance, since the projection is not only visible to the user but also to other people at the same location. This study draws clear conclusions regarding human-centered design of indoor navigation systems: "the user demands reliable, valid and easily understandable navigation information that protects him/her from disorientation and from elevated cognitive effort while decoding, transforming and applying navigation information, and is trustworthy enough to be followed" [41]. These conclusions are equally valuable for outdoor navigation devices.

To overcome the issue of mobilizing vision while walking and more particularly to assist elderly and/or visually impaired people in indoor environments, Tsirmpas *et al.* [44] have developed an indoor navigation and obstacle avoidance system that uses voice guidance. The system includes two main components: a wearable module and a localization/navigation server. Both modules run continuously and exchange information through a wireless access point. It uses radio frequency identification and assumes that the floors are equipped with the required tags. This solution falls into the terrestrial infrastructure based category. It enables user's localization, as well as navigation considering scenarios that the user might follow. It also suggests guidelines for self-navigation and obstacle avoidance. To evaluate the feasibility of the proposed architecture, four blindfolded volunteers were recruited. Results indicate that the system proposed is suitable enough to guide elderly people through an unknown built environment. However further studies, involving more volunteers, are required to assess their acceptance and behaviors regarding such indoor navigation system, their attitudes and intentions to use and buy it.

D. *New Perspectives for Researchers and Engineers*

Answering challenges, which are linked to the need for a technology that is adaptive and flexible for each situation and user, is identified as important [20], [32]. But within the research field of pedestrian navigation aids, the impact of individual differences, especially in functional abilities, has not yet been systematically studied. Comparison between different

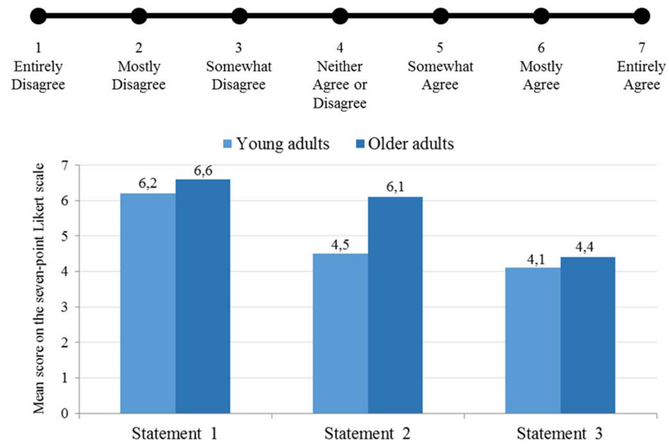

Fig. 3. Results of the questionnaire we developed about geopositioning technologies.

age groups or between men and women are often omitted even if these factors are known to influence navigational skills [45], [46]. Although some solutions are available for specific user groups with special needs, such as visually impaired people or older users [41], a systematic inclusion of relevant user's factors such as cognitive abilities is still missing. Research in the field of navigating in electronic documents has shown, for example, that users with low cognitive abilities face more problems in interacting with computers and in finding information on the Web [47]. To overcome these issues, several pertinent solutions are now available to satisfy most of users 'needs and abilities when searching for information on the web (e.g., query extension, "I'm feeling lucky", etc.). Pedestrian navigation tools development and commercialization requires really and quickly adopting a human-centered design position in order to consider individual differences in cognitive abilities. But, more generally, it requires adopting a universal design position to produce systems that are useful, easy to use and acceptable to everybody. Kjeldskov and Paay [29] recently highlighted a separation of research in mobile human-computer interaction into "two camps primarily interested in *people* or in *systems*" that is consistent with this multidisciplinary research filed. A first step toward the adoption of a holistic approach and finally the production of a universal pedestrian system is to go beyond this separation.

Another important issue is to inform users about the operating mode of such navigation systems and communicate about their advantages and limits to allow them to adopt the technology and make it part of their daily life experiences. Knowledge helps appropriation. In a questionnaire that we proposed to 20 young adults (age 21–45, mean = 27 years, 10 men and 10 women) and to 38 older adults (age 61–80, mean = 71 years, 17 men and 21 women), respondents declared to globally agree with the following statement "The GPS receiver's location is sent to the user by the orbiting satellites". On a seven-point Likert scale from 0: entirely disagree to 7: entirely agree, young and older respondents gave very high scores (around 6, statement 1 in Fig. 3), suggesting that all participants had wrong knowledge about GPS technology. Respondents also gave contradictory answers. To the statement "I have no problem with being geo-located in my environment" (statement 2 in Fig. 3), young and older adults had mean scores over 4, suggesting that most of respondents, and particularly the older ones, agree to be localized during their displacements. But during the interviews, the majority of respondents declared to be afraid of losing their individuality and autonomy when using navigation aids. They also gave neutral opinions to the statement "Confidentiality of my travels is more important than the benefits brought by a GPS", with mean scores around 4 for young as well older adults (the answer modality 4 meaning neither agree or disagree, see statement 3 in Fig. 3). Respondents globally expressed a lack of knowledge, a feeling of fatality and therefore powerless; development and commercialization of mobile navigation devices being so rapid and massive that they had no choice but to adapt to them.

Following the evolution of visual-based technologies, interest in augmented reality to deliver navigation services increases, but research results are not necessarily positive. A recent study showed that navigating with augmented reality (by overlaying digital navigation information on the user's smartphone camera view) can lead to the worth results as compared to using a digital map, or verbal guidance [48]. This study comprises two field experiments with 48 participants between 22 and 66 years old. Participants needed longer time to complete the navigation tasks with the augmented reality interface. More frequent and longer stops have been observed. The task load was rated higher and the system usability was rated lower. Severe problems were observed with regard to the handling of the smartphone while walking. For instance, some participants continuously looked through the camera view of the device and had a high risk to stumble because of missed obstacles. Smart glasses may overcome such negative results, but to our best knowledge, no study has yet been carried out on that purpose.

Another important question is actually to provide systems that do not interfere with the main task they are designed for. Walking requires both vision and audition senses and using such sensorial channels to provide help could produce interference effects and jeopardize safety. While interacting with a map interface provided by a smartphone or with a speech-based audio system, the user's attention is almost entirely on the device and they are potentially unaware of any physical dangers or obstacles around them. This is even more the case for elderly people with impaired sight or hearing.

Haptic technologies can potentially be useful in this context since they provide information while freeing the users' hands, ears and eyes. Haptics is a feedback technology that takes advantage of the human sense of touch by applying forces, vibrations, and/or motions to a haptic-enabled user device such as a smartphone [49]. Haptics has also proven to be very efficient in reducing reaction time, attentional load [50] and distraction [51]. Several haptic prototypes have been developed to assist people in their navigation through vibrotactile directional messages or alerts [50], [52]–[54]. For example, Jacob *et al.* [49] shows that users can successfully navigate from an origin to a destination point without using visual cues, like a list of landmark images along the way or a panoramic view of the destination thanks to haptic feedback, when the vibration alarm of a mobile phone held in the hand or left

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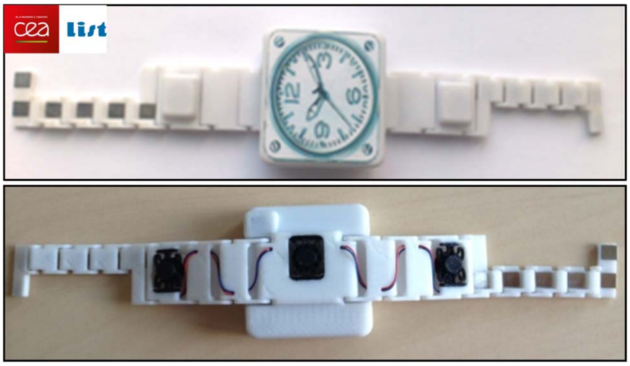

Fig. 4. Haptic wristband developed by the CEA-LIST, France [53].

in the pocket (with varying frequency and pattern) is used to convey navigation instructions. Moreover, memory recall of the environment was shown to be improved while using haptic feedback as the navigation mode, compared to landmark images based navigation.

If these technologies have already proven their usefulness for younger individuals [55] and visually-impaired individuals [56], the situation is however different for older adults whose specific needs for a haptic navigation aid have seldom been investigated. The same is valid for the design of haptic patterns that would have to be both acceptable and efficient for the elderly. Arab *et al.* [57] recently designed a set of haptic patterns for and by elderly people based on a user evaluation that was conducted to assess the recognition rate of these patterns during urban environment navigation tasks. Fig. 4 shows the developed prototype: the haptic wristband involves three actuators strategically placed around the wrist (left, right, and top), whereas the microcontroller and the power circuit are located under the watch face. Fourteen elderly participants took part in the study. The results showed that repetitions of a sequence within a pattern were not crucial for their discrimination and recall. On the contrary, they can cause memorization difficulties and confusion. Results provide a number of recommendations for the design of haptic patterns adapted to older adults' needs. Additional studies shall continue to explore this means in order to help older pedestrians to navigate in unknown environments using haptic feedback.

Vibrotactile cues can finally be a worthwhile means to provide private information in an easy to understand manner for the user. Whereas some solutions broadcast visual information on the ground that are visible to everybody, or others provide personal audible feedback to the user that possibly cut him from the rest of the world, haptic feedback represents an interesting way to meet practical requirement but also legal and ethics issues when designing pedestrian navigation systems.

IV. Ethical and Legal Challenges

A. Connected Objects: Legal and Ethical Aspects

The growing part of digital technology in daily life and the massive deployment of smart objects over the last few years have reshaped our environment. We have entered the era of "context awareness" for connected human [58].

Accessing online services, wearing connected objects (wristbands, watches, smart or contactless cards) and using smartphones or other digital tablets offers compelling services and can even save lives. Everyone can benefit from this development. The wristband "Embrace", presented at the 2015 Consumer Electronic Show, is a good example since it measures daily and night activity, epileptic crises and sends alarms when a significant health related change is observed. But this evolution often involves strong intrusion into privacy and beyond this, into personal data such as health data. These technologies have also the ability to locate persons on geographical maps, regardless of their will. Activities, i.e. walking, sitting in car and daily travels, are tracked with smart wearable devices that are sending location data to IT servers. Globally, travelers are leaving tracks on servers in return for information or service without knowing where the tracks and data are hosted and by whom or how they are processed.

Sometimes, geo-positioning functionalities are necessary to operate the services. It is the case for navigation applications, tour guides and location based services (LBS) that deliver information about the best restaurant, cheapest hotels, latest fashion shop or social networks [59]. The risk is that combining LBS with personal data may become highly intrusive [60]. The combination of mobility tracks and personal data provides important clues about personal life, personality and digital profile.

Today's main support for transmitting these data is the smartphone. Two studies about smartphone applications have recently demonstrated the limits of personal data protection on this device [61]. It is observed that 31% of the installed applications accessed the International Mobile Identification Number (IMEI) and 17% to the International Mobile Subscriber Identity (IMSI) without specific needs. IMEI and IMSI are unique identifiers stored in the SIM card. Over 3 months, a weather application accessed 1,560,926 times to location data and connected 341,025 times to the Internet. Consequently, context aware technologies raise questions about the acceptable limits on personal intrusion, especially when the control of personal data and digital identity should belong to the user.

It is expected that the system operator does not impair fundamental rights, such as freedom of anonymously coming and going, respect of personal data and privacy, etc. A right balance between protecting the users' rights in a globalized and connected environment and supporting technological developments should be targeted. One strategy is to already address protection issues at the design level of new solutions, following a "privacy by default" approach. This approach is recommended by the forthcoming European regulation on personal data protection ([62] art. 23, recital 26) that is being debated since 2012. French law and more broadly European rights give individuals fundamental rights priority. The vision that considers natural person only as consumer in a digital world is generally rejected by the European rights and personal data is rather considered as an attribute of the personality.

B. Personal Data Defined by the Ability to Identify Persons

The Community law [63] defines location data in the article 2c by "any data processed in an electronic communications

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network or by an electronic communications service, indicating the geographic position of the terminal equipment of a user of publicly available electronic communications". It is acknowledged that location data can be used to identify persons and profile them. Consequently, location data meet the legal definition of personal data. Indeed, timestamped geographical coordinates of connected objects reveal the locations of the objects and therefore their owners at any time.

Personal data has been largely defined by the European legislation (European Union, Europe of human rights, national laws) and it goes beyond privacy. It is characterized by the possibility of identifying a natural person, his/her attributes, profile and digital identity [64]. According to [65], personal data means "any information relating to a natural person who is or can be identified, directly or indirectly, by reference to an identification number or to one or more factors specific to them. In order to determine whether a person is identifiable, all the means that the data controller or any other person uses or may have access to should be taken into consideration". This definition is shared by the Community law [66] in article 2a, which also refers to an "identification number or to one or more factors specific to his physical, physiological, mental, economic, cultural or social identity" [67]. As such, IMEI or MAC (Media Access Control) numbers are direct identifiers of communicating objects. The status of IP address is still unclear but it was recognized as personal data by the Court of Justice of the European Union in the case Scarlet Extended against SABAM [68].

The European Parliament set up the Article 29 Data Protection Working Party (Art.29-WP) in 1995 to advise independently on the protection of individuals with regard to the processing and transfer of personal data. Representatives of EU countries constitute this Working Party. This group recognizes the association of location data with personal data. An opinion says that smart mobile devices are "inextricably linked to individuals" and "it is usually possible to identify them directly or indirectly" [69]. Thus, communicating and smart mobile objects are both able to identify users, possibly impeding the freedom to travel anonymously. Indeed, even origin and destination geographical positions can be sufficient to identify individuals, especially when observing commuting travels in partially urbanized areas. Globally associating "non-location" data with location data can be very powerful for identifying persons even if none of the data processed individually could be used to identify individuals. Data mining, inferring or combining anonymized location data can become personally identifying [70].

Once personal identification is obtained with location data, many other personal attributes become available using additional records [71]. For example, pedestrians entering into buildings thanks to a badge, LBS users or public transit travelers at a control point offer all profiling possibilities. For many service providers, such as LBS, personal identification is essential to access other personal data including the answers to: What am I doing? Where am I going? Who am I? Location data combined with regularly frequented places or usual transportation routes are all features useful to build individual profiles, which are then refined with other data: age, sex, biometric data, etc.

When the identification is not specifically needed, accessing these data violates the individual rights. This is the case when a third party has unauthorized access through a security breach or when the collected data are not required to achieve the objectives. It is the case of mobile applications (i.e. apps) that access to location data without requiring it to deliver the service. Some services (e-business, online banking, e-administration, social networks, LBS) must identify or authenticate the customers. Every individual is building one or even several digital identities in the digital world depending on the personal data recipient, the targeted goal and the expected visibility in online networks [72]. The digital identity is characterized by a username, a password, an email address completed by additional information, which are communicated to a service, a site or by users. This identity is not necessarily linked to the civil identity but it is sufficiently stable and secure for enabling the service providers to authenticate the user and to check for misused identity. Globally, all available information about a person is shaping his/her digital identity.

Identification features (identification or authentication data) shall be differentiated from other personal characteristics: visited websites and apps, connected bodies, or personality elements that correspond to virtual profiles. Pseudonymization of identification data is often required by law and supervisory authorities, implying data encryption mechanisms [73]. It cannot be considered that using connected objects implies that the user has given explicit consent to the transfer and processing of all personal data available to the service provider. In the absence of appropriate information, users often ignore the device operation mode and the possible security breaches affecting their personal data and privacy [73]. This phenomenon is effectively observed in the answers given by the 58 young and older adults to the questionnaire presented in Section III-D and that was developed to understand possible issues related to the usage of navigation technologies.

C. Location Data: Personal Data Under Surveillance

Location data have become increasingly sensitive data due to the inherited identification options and the exponential growth of connected objects. Information and consent are two of the personal data protection legal tools provided by the European legislation and some national laws. France is one of the most protective nations since 1978 [65]. Reminders on these rules are regularly delivered by the protecting authorities, which are the European Data Processing Supervisor, the Art.29-WP and the French CNIL [74]. The use of location data is controlled by many legislators and supervisory authorities in Europe [69], [73]. Accessing to location data without consent must be supervised if no legal basis explicitly authorizes it [75] or if it is not performed under the control of a judge [76], [77], even if it is motivated by legal proceedings.

In Europe, but also in other countries like Canada, the use of traffic data for operating mobile phone services or for other goals are differently addressed by personal data protection rules. They consider all purposes: legitimate purpose, necessity and proportionality, legal basis for the processing, security and confidentiality.

In Europe, the 2002 directive on "privacy and electronic communications" [63] incorporates the protection principles that are embedded in the 1995 directive on "publicly available electronic communications services" [66]. Traffic data that are necessary to operate mobile phone services are distinguished from those needed in added value services (LBS). Mobile phone subscription involves the consumer's consent to collect and process the data that are necessary to operate the services but not their use for different purposes [78]. Globally the purposes must be specific, explicit and legitimate. Lack of consent is only permitted with binding legal grounds, for life critical issues, for the execution of a specific contract, for public service missions or for the data processor's legitimate interest, which is difficult to define ([65] art. 7, [66] recital 30 and art. 7). In all cases, the rules must comply with the legal requirements that protect individual rights.

The data, which are necessary to fulfill the requirements of a service, are defined by its purposes. The data must be adequate, relevant (principle of necessity) and not excessive as compared to the purposes for which they are processed (principle of proportionality). This explains why data cannot be used for any other purpose without the explicit consent of the person of interest. The extension of the purpose is sometimes made possible, especially for historical, statistical or scientific reasons. The current European Regulation draft permits later use of data for other purposes without consent, provided that the purpose is not incompatible with the original one ([62], recital 40, art. 5b and 6-3bis) but this extension is still debated.

In practice, location data are frequently retrieved, especially at the application launch, even if it is not needed to run the app and the user's consent was not given [61]. This request does not always meet the legal obligations of data controllers and is not always legitimate. For example, the use of geo-located traffic data can only be legitimated by the service operation and by the contract bidding the subscriber and the operator. Naturally, the contract must comply with legal and regulatory requirements including the European Directives [63], [66]. However these traffic data cannot be used by the mobile phone operator, to provide added value services such as passenger transport management, nor can they be transmitted to third parties, which is often targeted by transport applications. Consent must first be obtained.

The consent means "any freely given specific and informed indication of his wishes by which the data subject signifies that their data will be processed" [66], art. 2h. Freedom is established by the ability to withhold the consent or to "opt out" at any time. In the case of connected objects, the "opt-in" method should be preferred since it allows the user to voluntarily and easily activate the service and to similarly deactivate it at any time. Automatic disabling could also be applied as soon as the application is not used. Questions about the consumers' degree of freedom arise when the access to a service is conditioned by the automatic consent to personal data over a certain period of time. This is for example the case when an operator offers several months of free personal data hosting, some of which might be identifiable and could be used illegitimately.

The principle of transparency embodied in the disclosure of information allows the person to give prior informed consent. This information must be complete, accurate and accessible. It must address the purpose of recording data, how the information is processed (what the person is consenting to when selecting "I agree" before accessing smartphone services) and the data recipients (who has access to what and for what). The accuracy and access to the information are essential but the actual operation of mobile applications reveals shortcomings in this regard. For example, how can pedestrians, downloading a navigation application while walking, acquaint themselves with the legal scope of the privacy policy? In 2004, the Art.29-WP proposed to introduce a stratified system allowing the person to choose the appropriate level of details [79]. In its current state, the future European regulation on personal data protection adopts the concept of explicit consent, inducing a reflection on how to express this consent (written form, "opt-in" rules based on boxes to tick) but first, on the quality and the accessibility to the information.

When the access to personal or identification data is required by the process, security and privacy means must protect the users to prevent intrusions and illegitimate or malicious uses of personal data. Technological design can insure proper security conditions either using proven pseudonymisation tools or developing solid IT security systems. These protection tools must be completed by confidentiality requirements that are defined by the data recipients (written commitment, internal rules, etc.) and anticipated at the conception of the device and services. This translates into the "by default" principle of "privacy by design", which is recommended by the forthcoming European regulation [62], art. 23. Proactive protection measures, automatic protection and transparency of the operations are all embodied in this regulation. Privacy by default design insures that only the data, which are needed to achieve the targeted purpose, are collected and processed. It sets personal data protection and privacy at the core of the operation. Only a fully compliant privacy by design system or irreversible data anonymization can release the service providers of all constrain. Identification data must be irreversibly anonymized when the data are no longer needed or the user no longer wants to use the solution. The legislation pays special attention to the data retention period [65], art. 6, 5°. In 2009, the European Data Processing Supervisor analyzed the draft Directive on Intelligent Transport Systems and stated that "for personal data to be processed anonymously, there must be no possibility for any person at any stage—taking account of all the means likely reasonably to be used either by the controller or by any other person—to link the data with data relating to an identified individual" [80]. The "right to oblivion" is not expressly laid down in the forthcoming European regulation and higher priority is given to "the right to erasure" ([62], art. 17).

In today's context of global connected services and Internet, it will probably be difficult to achieve irreversible anonymization and a genuine right to oblivion. Personal tracks are already present in manifold servers distributed around the world. Consequently, it is important to define rules especially when headquarters of the data controller are located in countries where personal data and privacy rights are less protected. Art.29-WP already pointed out in 2005 that the 1995 Directive rules on the transfer of personal data to third countries must be applied to the added value service providers that are not established in a member state of the European Union. In practice, this is difficult to implement for many LBS. The forthcoming European regulation proposes to better address territoriality problems: appreciation of the protection level provided by third countries (recitals 81, 82); national supervisory authority to exercise its powers on data processing performed by an organization, which is not established in the EU but targeting persons that are established in the territory of the State member governing it (recital 95bis, Art. 2).

D. A Good Personal Data Protection Management, a Legal Certainty That is Guaranteed for All Those Concerned

The development of smart mobile systems and the increasing inherited intrusion risks (traveling pattern knowledge, lifestyles analyzed using daily traversed spaces, etc.) raises debates about location data [81]. In France, location data processing requires a declaration that must be filed at the CNIL, but no authorization is required. Globally, legislative changes aim at better controlling the use of location data to better deal with the rapid growth of connected objects for personal mobility.

The growing importance of personal data protection and the sanctions incurred if the regulations are not observed should encourage private and public professionals to set specifications for each system, considering all procedures, rules, emergency control recommendations at the design and management levels. This is comforted by the forthcoming European regulation that should hold professionals accountable to their responsibilities with the introduction of stricter rules. Prior formalities with the data protection supervisory authorities should be relaxed but the principle of accountability will reinforce responsibilities, asking them to provide evidence, upon request of the supervisory authority, of the measures that have been taken to protect the rights on personal data. A complete set of actions is proposed, such as a risk analysis and the privacy impact assessment (PIA) of collecting personal data, the scope and purposes of these records for large scale data collection and more particularly behavior data ([62] art. 33). A draft of ISO standard that will require the data controller to produce a complete documentation prior to any data processing is under preparation [82]. Even if sanctions are already imposed by supervisory authorities or judges, they often prove to be insufficient. The maximum criminal fines for violation of human rights resulting from computer files or processing does not exceed 300,000€ in France (Penal Code art.226-16 and following). A positive impact on personal data protection is expected from the future European regulation that plans to introduce administrative fines up to 2–5% of the annual worldwide turnover ([62], art.79 bis).

Beyond consent and personal data protection, studies show that the restitution of data to the user will strengthen the confidence in the digital world. This notion of confidence was introduced in 2004 in the title of a law intended to accommodate the growing demand of digital economy. The goal was to increase the confidence in using new information technologies and to strengthen the growth of this sector [83]. Innovation and confidence are two parts of the equation on Digital Rights and Freedoms. The French Minister announced in early 2014: "Trust is central to the development of the digital society and economy and for the extraordinary development of digital innovation. It is a major issue for both our society—Edward Snowden's revelations had the merit to form the basis for discussion—and our economy, because without trust, the digital economy won't further develop. These are the two inseparable pillars of our digital policy: innovation and confidence" [84]. A major consultation on the digital world, managed by the French National Digital Council, supports the future Digital Act. A report that is built around 70 recommendations including the "fundamental right to digital-determination" and that had already been advocated by the Council of State in 2014 [85], [86] was submitted to the Prime Minister in June 2015. It intends to provide individuals with greater control over the processing of their personal data without moving into the legal system of real property, which could deprive them of all rights on personal data in the event of disposal. The right to digital self-determination was also introduced in a census related decision, given by the German Federal Constitutional Court in 1983 [87]. It is linked to a data portability right: the right to retrieve personal collected data for other possible personal usage.

These proposals meet the recommendations of the FING [88], which is paying close attention to the implementation of new technologies that respect users' rights. A recent report [85] demonstrates the importance of returning personal data to the individuals. In the forthcoming European regulation (art. 14e), existing access rights, objection, and rectification shall be completed by the portability right. This should also contribute to the civic takeover on the digital world pursued by the French Digital Council. The public consultation that precedes the drafting illustrates this strategy.

V. Conclusion and Perspectives

Research and development have been conducted on individual positioning and navigation systems for personal mobility for more than a decade but no universal solution is available yet on smartphones, i.e. a solution that is accurate, robust, useful and acceptable to everybody, ethic and continuously available. An original transdisciplinary study of the underlying reasons including engineering, human and ethical dimensions is proposed to progress toward this solution, which has a strong potential for the economic and digital growth. Indeed, smartphones and wearables generate already more than one billion dollars market. In this paper, an analysis of the reasons for the absence of a universal navigation solution is proposed. It focuses on the engineering aspects, the human challenges and the European legal framework on location data.

Ongoing developments of geo-location technologies are mainly driven by added value services and possible illegitimate reselling of personal data. Alternative solutions are possible thanks to scientific breakthrough in the design of positioning and navigation algorithms including specific pedestrians' features such as the freedom of movement, the diversity of traveling motivation sources, deformable and evolutionary models of the human body and the chaotic/unpredictable nature of on-foot displacements. Sensors embedded in wearables devices are enabling this approach thanks to novel self-contained positioning and navigation methods allowing navigation in privacy. GPS is an outstanding illustration of this technology, since contrary to general belief the signals broadcasted by the satellites are processed by the receiver in an autonomous manner to estimate the location. All global navigation satellite systems but also inertial and magnetic sensors comply with the "privacy by design" and "privacy default" principles.

Research is still needed to really adopt a user-centered approach and account for the vast majority of users and contexts but also to favor the adoption and acceptance of new technologies. Existing human-machine interfaces are commonly using human senses needed to navigate, for example the vision on the screen of a mobile device or the audition with a headset. These senses contribute to the natural human ability to travel and their use by digital components may impair navigation capacities. Actually, the user's attention is almost entirely devoted to the media rendering the person unaware of surrounding physical dangers or obstacles. Finding alternative strategies such as haptic solutions combined with other means contribute to the development of a universal personal navigation solution. This is even more important when looking at the time evolution of the users' interaction with navigation tools. Globally new needs will emerge and they have to be perceived by product developers to propose new functionalities in return. Long-term use of such devices may also have counterproductive effects. Gradually, we may lose capacity to memorize itineraries and to navigate alone in known and unknown environments. Such devices are actually often seen by older adults as a barrier to the autonomy even if they can definitively contribute to increase the travel safety.

The analysis of the European legal framework on location data shows that a risk of private data violation is linked to the access to personal mobility tracks. Europe holds an international leadership in the protection of individuals from personal identification through data processing since it has now associated location data with personal data. Despite excessive lobbying, the Committee for Civil Liberties, Justice and Home Affairs (LIBE) of the European Parliament is reforming the data protection law that promotes "privacy by design". Engineering development can follow a "privacy by default" path that would enable all travelers to benefit from advanced navigation systems, keep the control on their location data and navigate in privacy. Creating add-on solutions that preserve the confidentiality of geo-located data is costly and therefore sometimes of lower priority but sharing geo-located data may pose an inherent threat to the evolution of the society. Solutions are on the way but they definitively require a more interdisciplinary conception.

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