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For any user of public transport, the journey consists essentially of alternating sections completed as a pedestrian or riding as a passenger in a vehicle or other form of transportation. In transport hubs and interchanges, the complexity of the task of finding one's way requires the installation of comprehensible visual and audible information systems and signs for guidance and orientation. The design of these systems needs to take into account the requirements of all types of user and this is particularly critical for those with disabilities or any difficulties of mobility and orientation. Those with specific problems of orientation in public places, such as the blind or visually impaired, the hard of hearing, persons with reduced mobility and those with dyspraxia or cognitive disabilities can also be classed together with foreign visitors, since problems of guidance concern everyone who cannot perceive or understand the local language or codes used for visual or auditory information.

The widespread use of smartphones and the development of applications for guidance has increased the possibilities of providing personalized information for users and introduced the issue of optimizing the distribution of information between the visual, auditory or haptic modes and their use for ambient and individual orientation and guidance as well as for general transport information. The emergence of new technologies for outdoor and indoor localization and detailed geographical information systems with their associated data bases have facilitated the deployment of applications to prepare and guide users as well as providing support and aiding choices during any displacement or action. However the proactive nature of the guidance interface can quickly transform any errors in guidance or interpretation into "risk taking" which could quickly degenerate into a vicious circle of chaos and potential danger for the pedestrian part of the journey.

After working extensively on the analysis of requirements and the assessment of devices for guidance and information for the visually impaired and more generally those with sensory or mobility problems, we have developed a model of the needs of users of public transport, both urban and interurban (the Model SOLID, detailed in a separate presentation).

Using this model we have developed new criteria for the design and assessment of proactive guidance interfaces based on the concepts of humility and tri-coherence that are the focus of this paper.

We propose, define and clarify these concepts through the discussion of the design of different interfaces, which can be implemented on PC’s, tablets, Smartphones or ambient systems for the guidance and information of sensory impaired users of public transport. The methodologies adopted to assess the interfaces that meet or don’t meet our criteria have been developed through controlled experiments in real life situations with a protocol of tasks in a variety of conditions for testing different modes of interaction. These include the choice of the terms used for the interaction and dissemination of information and the grammar, vocabulary and indications of the confidence attributed to the information conveyed in the messages for the users. These experiments have shown the importance of this latter feature since we have shown that the system should have a characteristic of "humility" to indicate that it is incapable of giving reliable information when problems arise, or backtracking to a point where more precise data is available.

By taking into account the orientation of the traveller, the reliability of the information on their location and the information update processes, the interface can adopt different strategies to describe the scenario and suggest actions to guide the traveller. This must ensure that the mental image of the scene in the mind of the user and that described by the interface correspond as closely as possible to the real situation. This correspondence between the imagined, the described and the real situation is the new criterion that we have described as tri-coherence.
We present the main results of these assessments that illustrate and validate the relevance of the humility and tri-coherence criteria. The application of these criteria reduces mental stress and improves attention, reducing the chances of a lack of vigilance and subsequent errors, the most common reason for falls, shocks and collisions. The new criteria were developed and validated during tests carried out in seven projects in France with groups of 20 to 50 visually or hearing impaired persons and control groups in collaboration with the Paris Metro authorities, national rail stations in the Paris region and multimodal transport interchanges in the area of Lyon.

**Keywords:** Guidance, Orientation, Visually or hearing Impaired, Mobility, Transport.

1. Introduction

This paper deals with the problems of optimising the efficiency of systems to guide and orientate persons with difficulties of mobility, particularly the visually impaired, with an emphasis on the specific challenges of using public transport and multiple modes of travel. In cities, where the traveller is often required to use several different types of transport, such as bus, metro, train or tramway in addition to parts of the journey where he is a pedestrian or using a wheelchair or other form of personal mobility it is essential to achieve the highest possible accuracy in locating and guiding the user for multi-mode journeys, both outdoors and indoors, within the technical limits of the technological solutions currently available. A journey normally consists of a chain of displacements or an alternation of phases where the user is either a pedestrian or a passenger in some form of vehicle. The initial step on the outward journey starts with a pedestrian phase to enable the user to get from their front door to the first intermediate destination which would be a bus or tram stop, or in bigger towns, a station of the metro, underground or rail transport system. The first task of the system is therefore to guide the user to this initial destination in a reliable and secure manner, catering to the specific needs of the user in function of their type of impairment and the risks involved in case of any inherent lack of accuracy of localisation of the system being used. The introduction of smartphones and other interfaces capable of communicating the position and orientation of persons in a way adapted to their difficulties has increased the possibilities of solving many of these problems, including the possibility of communicating information via visual, auditory or haptic modes, but it is important to recognise that because of technical and human factors the system will never be 100% reliable and it is necessary to adopt strategies to ensure the maximum safety in all circumstances. The strategy must be devised taking into account the fact that if the system itself becomes lost then the messages communicated to the user should be optimised to permit the person to backtrack in safety and avoid any potential risk of putting the person in danger due to panic that could be induced in the user. This kind of situation can be avoided by improving the technology and accuracy as well as coaching the person to deal with such situations, but also by ensuring that the information communicated to the person in these circumstances is clear, easy to understand and induces confidence in the ability of the system to enable the person to backtrack from the point where the system has lost its bearings to a previous reliable reference point. The ideas presented here have evolved and been validated over several years through the participation and collaboration with many partners in seven projects dealing with aids to improve the mobility of visually and hearing impaired persons in bus, metro, tram and railway networks. The problems of using PDA's and smartphones to locate and guide the visually impaired to bus stops, and shared spaces were examined in two projects (RAMPE 2004-2006 and Infomoville, 2007-2010). Infomoville was extended to deal with the problems of tramways in 2010. "City guide" completed from 2007-2008 dealt with the specific problems of access to railways and their infrastructure, but without proposing a system for localisation. The problems of developing solutions for metro and underground stations were examined during the project DANAM, which was conducted in the period from 2008-2010 and evaluated systems using an inertial guidance system. Two further projects dealt with systems of delivering information for visually or hearing-impaired passengers using the Paris metro system. These projects, SIV1 and SIV2, compared the effects of testing two different styles and grammar when giving guidance information to the user in order to test which style was the most effective in maintaining safety.
2. Wayfinding and guidance systems for the visually impaired traveller.

Since the first commercially available GPS systems for personal navigation appeared on the market in 1989 the possibility of developing systems specifically catering to the needs of guidance for persons with problems of mobility and the visually impaired has attracted the attention of engineers and researchers alike. The development of initial solutions using a PDA connected to a separate GPS unit followed by the use of mobile telephones and later the arrival of smartphones integrating GPS has increased the possibilities of providing integrated technological solutions for guidance, communication and localisation over recent years. This has increased the possibilities of including different methodologies, functions and interfaces to cater to the needs of those with specific mobility problems, such as the visually or cognitively impaired as well as the elderly or those with other difficulties. The paper by Kurachi gives details of the programme developed in collaboration with the Japanese Ministry of Economics Trade and Industry to produce a Pedestrian Guidance System for the visually impaired and wheelchair users.

The need for higher accuracy than that provided by a GPS system and the requirement for guidance both outdoors and indoors has encouraged the development of systems based on the use of various technologies for localisation such as inertial tracking, Infrared, RFID tags, Bluetooth and iBeacons, WiFi, video cameras and LED devices as well as traditional tactile surfaces and pathways to assist and guide the visually impaired.

In France, in the context of guidance in public transport, the Mobiville and Infomoville projects using smartphones and tracking for guidance have been described in papers by Coldefy (2009) and Pretorius et al. (2010) and many other similar programmes have examined the practical and technical aspects of different types of solution. In order to cater to the needs of the visually impaired and deliver clear directions for the user, navigation systems using verbal description and instructions have been studied for many years. The papers by Bradley et al. (2005) who investigated the way the verbal information and directions were delivered to the user and the papers by Giudice et al., (2007, 2008) propose approaches, which are in conformity with the ergonomic requirements described by Bastien and Scapin (1993) to provide brief, concise and non-ambiguous directions. This is the area which has been studied in our experiments and has lead to the criteria proposed in this paper.

2.1 The representation or mental image of his environment for a visually impaired traveller.

We use the term "representation" for the mental image formed by the person during his journey despite the controversy that it can induce, because it is a process of mental construction of an image of the situation and at the same time the result itself. The information communicated by the guidance device is an ensemble of indices perceived, captured or extracted episodically from the static or dynamic environment forming an ensemble of observations contributing to this virtual reconstruction of reality.

This representation or the mental image that a visually impaired person has of his environment is an important factor, which can greatly influence their ability to use a wayfinding device. This is not the same as the real characteristics of the situation. The mental image of a person can change depending on their previous experience in a similar environment and if they lost their sight early or late in life. The different situations which are experienced by the visually impaired traveller and the agents working for the transport operators, mean that there is a need to ensure that the mental image of the traveller of the distribution of equipment in this space which can be very different from that provided by any technological device and the real environment does not prevent them from using the guidance system in safety. The HMI used by these new technologies must meet additional criteria, which have been developed during the experiments carried out in real situations with visually impaired subjects in different transport environments. (Humility and tri-coherence). The principal goal of any system is to provide reliable guidance and avoid any risk of accident, but the fact remains that no technology is perfect and we have to provide an answer to a fundamental problem. If the difference between the information provided by the technological device and the actual
situation endangers or misdirects the user due to false data or information, how can the user find his way back to a safe situation?

In order to investigate this type of problem, two experiments were made in Lyon with the network “TCL-Kéolis”. Two complex protocols combining real and false information were proposed to oblige the traveller to find a new route for their journey due to a simulated closed line. A model of the requirements of a visually impaired person, the Model SOLID: (Security / Orientation / Location / Information / Displacements), was partially presented in a paper presented at the conference STHESCA in Krakow (Uzan et al. 2011) and subsequently a more complete oral presentation was made at the ITS Transport in Orlando the same year. (Uzan et al. 2011). This model had been developed and validated in the course of the research and practical experiments associated with numerous projects in the period 2000 to 2009. As an example, the task of orientation comprises five elements: maintaining a straight line, following a path, reaching an intermediate destination, memorising and reaching a final destination and developing an alternative route. The full model also includes modelling the chain of displacements, motivation, dividing the space in zones, defining key moments of delivering information, the nature of this information and the conditions of deliver either ambient (on the platform for example) or on board the metro. The model explains from the perspective of the traveller, their perception of the different modes of transport and the relation with the potential errors of acquisition of information due to the conditions of access and transfer.

2.2 The influence of the architecture of wayfinding devices

The architecture of wayfinding devices is generally composed of three elements: a set of technological modules for localisation, a core processor for route calculations and communication interfaces providing the route information. The reliability of the first two components will affect the behaviour of the third. Reliable guidance requires not only the location of the subject with respect to a rectangular frame of reference but should also include the exact polar orientation of the subject about a vertical axis. In particular our experiments have shown that simple left or right commands are insufficient to correctly maintain the orientation of the user and that the most efficient method is to give instructions based on the hours of a clock face between 8 and 4 o’clock. Inertial tracking devices can provide continuous monitoring of position and orientation of the progress of the user indoors or underground, but the results are affected by sensor noise which results in bias and drift so that outdoors a compass can provide more accurate polar information.

The availability of compact inertial measurement systems based on MEMS technology has enabled their use for tracking the position and orientation of human subjects, but these, like all inertial guidance devices are affected by drift and bias and require frequent recalibration of the position and orientation of the device at regular intervals on the route. This can be done by comparing the position indicated by the device and the real position at a reliable marker reference point on the route. Reference points to verify the user's position and correct the estimation made by the system can be provided by using suitably placed Infrared transmitters, RFID's, iBeacons or other Bluetooth devices. Talking signs or modulated LED reference lighting can also be used. Alternatively, certain features of public transport infrastructure, such as escalators, lifts, ticket barriers or entries to platforms can be identified directly by the user and used to recalibrate the device. The errors of orientation or polar coordinates can also be corrected by asking the user to adopt a particular orientation with respect to these reference points. This could be to stand with his back to the escalator when he reaches the end or with his back to the lift on arrival at the upper or lower floor.

2.3 The human machine interface

The HMI should be optimised to prompt the user to perform the actions to correct for the bias in a timely manner to ensure maximum accuracy at all times during the journey. This requires a certain flexibility in the messages provided by the HMI and specific ways of communicating information adapted to the needs of normal pedestrians, to those with mobility problems and in particular those who are visually impaired to ensure safety and reduce risks. The HMI has therefore two additional functions, to initiate calibration procedures to ensure the accuracy of measurements of distance, position and orientation and give some indication of the accuracy of information based on the device characteristics and the time elapsed since the last calibration. This will also increase the user's awareness of the effects of drift and loss of coherence as well as the necessity to use caution in acting on the results. We therefore have to face the risks of a lack of confidence in the results, which may not correspond to the users own mental image of the situation and his true position and orientation in space. The user interface is not just a simple verbal guidance system
indicating the right path, but it is a system, which has to manage and avoid risks related to the reliability of the localisation, orientation and guidance of the user. In cases where there a lack of agreement between the user's own mental image of the situation, the information furnished by the guidance device and the actual environment in which the person operates, any error can generate a risk of a loss in orientation, a fall or a collision with grave consequences for the user.

If the messages are communicated as a sequence of brief phrases in a limited time, this pre-supposes that the user has sufficient memory capacity to understand the meaning, the ability to process the information, solve any problem posed and take the right decision or action in the time available. It is therefore necessary that the messages from the HMI should respect the ergonomic requirements of brevity, density and non-ambiguity but permit the user to maintain vigilant and aware of other indications of the true situation to avoid the lure of being unduly dominated by the information provided by the guidance and tracking device. In other situations, when listening to messages and performing other actions, such as driving for example, the risk of errors is increased by any difference or conflict between our learned procedures, which have become automatic and any message, which advises an action opposing our normal behaviour. This type of conflict between learned behaviour or habits, based on the previous experiences of the subject and verbal information provided by the device should be avoided. As previously mentioned it is necessary that the messages and grammar used by the HMI in wayfinding devices meet the requirements of interface ergonomics. With this in mind we have proposed two new criteria for the design and evaluation of the HMI of these types of devices, the criterion of Tri-coherence and the criterion of Humility.

3. The criterion of tri-coherence

The tri-coherence can be defined as the level of coherence or consistency between
a. the immediate or lasting maintainable representation or mental image that a person perceives of a situation in the context of his activity,
b. that transmitted by the human machine Interface of the technological device used for localisation and guidance and
c. the real situation and context in the environment of that activity.

The tri-coherence is therefore an indication of the reliability of information based on the multiple and mutual dependence of three representations or sets of parameters in a given context and not just a comparison of the consistency between two sets of information from two different sources. In the latter case the possibility of errors may still exist, because consistent or good representations may exist pairwise, for example if the user has a close or identical representation or image of the situation to that provided by the device interface, but there is a significant divergence with the reality. In the same way the guidance system could provide an accurate representation and information on the real situation and context, but the user has a different representation or image of the situation. The last possibility is that the user has an accurate image of the true situation and context, but the guidance device provides erroneous information. In each of these situations of pairwise coherence there is the possibility of inducing indecision or conflict with potential danger for the user if he is not fully aware of the true situation. This is of course particularly true for the first case where the device appears to give information that is in good agreement with the user's own mental image of the situation, but the reality is different and the user has no indication that there is a problem.

3.1 Causes of a lack of coherence with the mental image

The causes of these deviations of coherence or consistency of the user's representation or mental image of the true situation are varied and they may have several causes:

a. A lack of knowledge of real transport infrastructure, particularly for those with early onset visual impairment.
b. The effects of evolution and changes in the architecture of transport infrastructure over the years, for those with late onset impairment, but out dated memories
c. Through an undue reliance on the automatic reactions the person has acquired over the years in different transport environments,
d. Through the transformation, alteration, addition, omission or loss of elements of memory during the recovery process or long term memory loss of previous experiences.
e. From difficulties or failures to refresh elements of context in the working memory.
f. From failures to correctly perceive the environment, due to selective or inaccurate estimations of distance and position or a lack of attention to other sources of information.
g. From a lack of confidence in certain of his perceptive abilities or in the guidance device used.

![Diagram of tri-coherence](image)

**3.2 Causes of a lack of coherence with the guidance device**

The guidance device itself can give erroneous information if;
a. the quality and amount of data exploited by the device is insufficient to ensure its mission of assistance  
b. the information transmitted to the device is unreliable  
c. the reliability of procedures and processes to refresh, recalibrate and process data is insufficient  
d. the device is programmed to calculate a solution and give verbal instructions without caution even if the reliability of data is clearly insufficient  
e. the results presented to the user give the impression of higher accuracy than justified by the database used by the device

**3.3 Summary of potential solutions to increase tri-coherence**

Verbal communications or suggestions by the HMI for an action in the form of an order or a target to attain, give the impression of the infallibility of the device, or express a higher reliability than justified. This can reduce alertness or excessively increase the level of confidence of the user, making him take undue risks unconsciously. It is therefore necessary to emphasise the importance that must be attached to all three sets of information and remind the user of the possibility of potential errors, both directly and by the use of expressions and grammar which avoid precipitation and over confidence. The existence of sensor errors or insufficient attention to recalibration of the position and orientation during the voyage will also introduce more potential risks for the traveller. The user must be encouraged to participate in the tasks of recalibration and optimisation of the parameters of the device and collaboration with the decision making processes in order to satisfy the criterion of tri-coherence and ensure a risk free and speedy journey.

**4. The criterion of Humility**

Devices for wayfinding have become more and more complex over the last few years and are increasingly based on the fusion of information from many types of sensors and delegating tasks to intelligent agents. The tendency to put undue trust in the information communicated by the system, even if there are indications from the user's own senses and experience that it does not totally correspond to the user's own mental
image of the situation can be a potential risk. The way the information is communicated to the user should reflect the fact that systems are never 100% reliable and there is always a possibility of error, either in the information supplied, due to database or sensor problems, the user's comprehension of this information and overconfidence. The criterion of humility, which should be exhibited by the Human Machine Interface is proposed as a means of limiting these risks.

To meet this criterion, the interface must be designed to respect the following principles -

a. When the interface communicates information or instructions calculated from sensor data or external databases, it must also be capable of indicating either by its form of communicating or by another means the level of confidence or reliability that can be attributed to its results.

b. When the data sources are based on real time acquisitions the system should be able to indicate the delay between last update of information from the sensors or other data and the present time. If information is derived from a database it should be possible to indicate the time these data sources were last updated.

c. The behaviour of the HMI must not generate additional risks by appearing too confident of the information given, which could reduce the user's vigilance. The use of expressions or commands, which are too directive or give the impression that the user's skills and senses are insignificant in comparison with the system, should be avoided.

d. The HMI must not allow the user to assign a capacity or knowledge to the system that it does not have. If the reliability of data is inadequate or there is a lack of sufficient up to date information to proceed without risk, this should be clearly indicated by the system.

e. Any interface suggesting tasks to accomplish during a journey must avoid using the imperative to dictate directions to the user, except to stop him when extra vigilance is necessary or the risks resulting from a false action could be critical. The use of the conditional instead of the indicative to communicate information in vocal or displayed messages, will ensure that the user does not become over confident in the reliability of the data collected and communicated by the interface particularly when the quality and quantity of data for localisation is insufficient. This should encourage the user to stay aware of other clues in his environment and compensate for situations where the data is apparently clear, but the reliability is insufficient. To avoid giving the user the illusion that the precision of the system is greater than justified by the accuracy of the device it is often preferable to reduce or limit the accuracy of the information provided, to encourage and maintain user vigilance.

f. Include an emergency system to take over control of the device after any potential breakdown during the guidance process. This should be continuously updated and capable of indicating the succession of tasks necessary to ensure safety, such as backtracking one's path, if a breakdown occurs.

5. Application of the principles of tri-coherence and humility in the HMI

These criteria can be complied with if it is possible to intervene and control some of the parameters of the device to obtain an indication of reliability of the data being processed and if necessary, enable users to increase their level of control over the system. The delegation and sharing of tasks opens up the opportunity to develop tools for the human machine interface where the user can intervene and better understand situations where errors may occur. Tasks such as recalibration of position and orientation and optimisation of the parameters as a function of the user's abilities and the environment would be areas where the user could gain a better appreciation of the potential for reducing errors. It is this type of opportunity for development that, from our point of view, the criterion of humility derives much of its importance.

Following a number of projects and experiments conducted in different environments with different systems and parameters it was possible to construct a guide for the language and style of messages needed to communicate with the user and integrate the criteria we have suggested. The following situations show for example how the communication of information can be modified (translated from French). The timing and initiation of an action should always be presented using the conditional in order not to incite an action without reflecting on other clues to possibilities of error. "Go forward 10 metres" is relatively brief and clear, in accordance with the ergonomic requirements for concision, clarity and brevity, but if the initial orientation is faulty this could lead to danger and "about 10 metres" or "about 12 steps or paces" gives an indication of potential imprecision and the necessity for caution. The parameters for the length of each step could be adjusted specifically for the physical characteristics of the user, but the length of each step can vary according to the circumstances and it has been shown that users measure distance in terms of time rather than by counting steps. The correct orientation can be indicated using natural references such as the direction that the user is facing as he arrives at the end of an escalator or exits from a lift if no orientation or
reference device is installed in that area. Directions should also be indicated by reference to a clock face (about ten o’clock for half left for example) since trials have shown a significant increase in precision and speed with this approach. Targets should not be set with respect to a described plan or layout since this will confuse the user who should proceed step by step and frequently stop to check their position and orientation at strategic points if prompted by the HMI or if he has doubts that he has arrived at the correct milestone.

6. Conclusions

Through experimental testing and validation in situ it has been shown that the development of appropriate modes of communication for the human machine interfaces of guidance devices using intelligent agents and advanced techniques of wayfinding can improve the safety and reduce risks for persons with reduced mobility. Two new criteria are proposed to improve performance and define the appropriate forms of communication with users of wayfinding systems. The criterion of tri-coherence is defined as the level of coherence or consistency between the representation or mental image that a person has of a situation in the context of his activity, that transmitted by the human machine Interface of the technological device used for wayfinding and the real situation and context in the environment of that activity. Methods have been proposed to increase the user’s awareness of the necessity to take into account these three factors and use the HMI to indicate any potential sources of inaccuracy in the information transmitted by the system as well as encouraging the user to actively participate in the decision making process.

The criterion of Humility is directly linked to the form of communication used by the HMI and is designed to encourage caution and reduce the possibilities of placing too much trust in the results and information provided by the device. This is achieved by avoiding the use of the imperative in instructions given to the user. The preferred way of communicating with the user is in the conditional, except when an imminent danger is detected, or it is vitally necessary to warn the user to recalibrate the system. Examples are given of the types of expression that can be used and the improvements in performance that have been noted when these criteria are applied. These criteria can be applied to all the communications and directions provided by the HMI to the user.

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8. References

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