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Towards Transparency Between the Autonomous Vehicle and the Pedestrian

Abstract

This paper addresses the new problem of transparency in relation to pedestrians' interaction with driverless vehicles, arising from their lack of visual cues to replace those currently provided by the visible behaviours of the driver. It reports two observational investigations of the *affordances* of the street, one looking at the street as static environment, the other at pedestrian behaviours in relation to driven vehicles. The findings of the research were used to identify the decision-making process, timings and exhibited behaviours of pedestrians and drivers in the street environment.

Keywords

Transparency, Interaction Design, Behaviour, Street Environment

1. Introduction

The field of autonomous vehicles (AV) has recently received considerable attention with the rapid development in the industry both by traditional automakers such as Jaguar Land Rover, Nissan and Volkswagen, and leading innovators from other fields such as Google, Lyft and Uber. In spite of the increasing capabilities of autonomous vehicles, such as environmental sensing, object detection and compliance with rules, their ability to react to unexpected situations is still questionable [1]. On a more general level, Zimmerman[2] explains the competent use of a given rule. He mentions that the usage of rules is dependent to the state of normality as the unpredictable occurrence of situations threats the production of desired outcomes. From this point of view, the deployment of autonomous vehicles in the urban environment is still a concern on safety grounds. There is evidence that some types of pedestrians have low levels of confidence in interacting with driverless cars [3].

Companies in the automobile industry were said to have invested in safety-related technology around $80bn dollars by the end of 2018 [4]. Much of the research is concerned with low-level interactions, disregarding the complexity of the urban environment. Autonomous navigation in a busy urban street environment is currently a challenge for driverless car innovators due to the unpredictability of the bidirectional interaction between humans – particularly pedestrians – and autonomous vehicles. The research reported here contributes toward this longer-term goal through research into pedestrians and driver behaviours in the existing street context. This is a prerequisite for understanding how to design more transparent autonomous vehicles whose behaviour is more easily predicted.

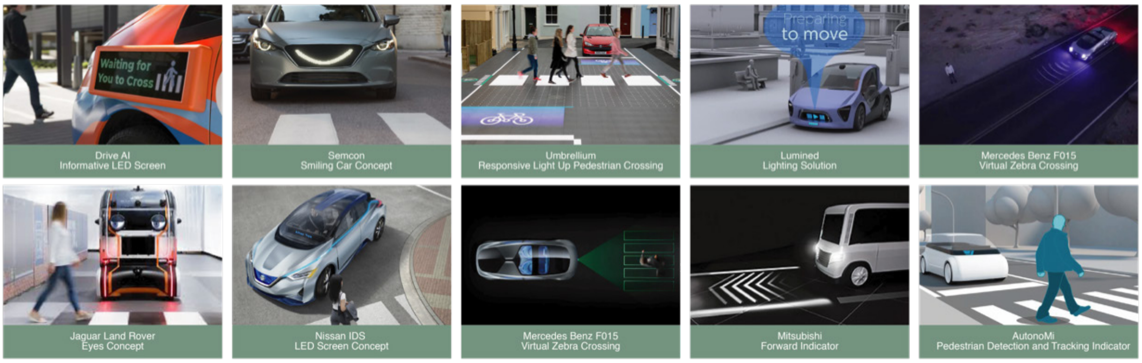

Fig. 1. Designs for autonomous vehicles or streets to improve the pedestrian crossing situation. The products in the pictures are designed, respectively, by: Drive AI, Semcom, Umbrellium, Lumiled, Mercedes Benz, Jaguar Land Rover, Nissan, Mercedes Benz, Mitsubishi, AutonoMi.

2. Key Concept: Transparency

We first introduce *transparency* in our context, then overview relevant interaction design centred on autonomous vehicles. Research in intelligent systems and human interaction shows a clear demand for transparency [5]. Much of the debate is around making machine intelligence accountable [6][7][8] with emphasis on their being transparent *after the fact*, though the need for *intention* to be perceptible is also acknowledged as important, which may include designing intelligent machines so that their general appearance allows their genre of action to be predicted [9]. Our interest is in transparency immediately prior to and during the interaction. Kirsch [10] describes the interaction between two parties as transparent when the user, in our case the pedestrian, with a certain amount of information may understand clearly what actions an object affords. Each party gains understanding through sharing information clearly and intentionally with the other [11]. An important consideration is the optimum amount of information-sharing to reach a satisfactory level of communication [12]. Overloading individuals with information is not desirable in many contexts, but especially when rapid and effective decision-making may make the difference between life and death or serious injury.

2.1 Designs to Increase Transparency of Autonomous Vehicles

When a pedestrian observes a traditional driven vehicle, much of that vehicle's imminent action is predictable because the pedestrian sees not only the vehicle but also the driver. The pedestrian reads the posture, gaze, gestures and expressions of the driver. The vehicle-driver system taken as a whole is productively transparent. If the vehicle is wholly autonomous, however, these key indicators are missing. The vehicle has become *opaque* and its imminent actions are no longer predictable. In the image above, we can see several recent attempts to overcome this problem. In the projects of Drive AI, Lumiled and Nissan, messages inform pedestrians textually of the vehicle's intention, while the smiling-car concept expresses itself through a human-like gesture of smiling to communicate with pedestrians. Another anthropomorphic imitation by Jaguar Land Rover applies moving eyes to the vehicle. The Autonomi concept detects and tracks pedestrians and re-communicates this data through its LED lights. Mitsubishi, Mercedes Benz and Umbrellium concepts instead focus on signals from street signage design.

2.2 Conceptualizing the Problem

Theoretical insights relevant to the problem include those of phenomenology and ethnomethodology. Merleau-Ponty's analogy of the player's navigation and exploitation of the football field [13:168] is particularly relevant to the dynamic, emergent, often antagonistic negotiation by pedestrians, drivers, and others, of the streetscape. It echoes Gibson's [14] concept of affordances and his emphasis on embodied cognition within dynamic contexts. Garfinkel's ethnomethodology is useful for its emphasis on the emergent production of acceptable and effective behaviours, for example

Fig. 2. Panoramic Photo of Exhibition Road

Fig. 3. Panoramic Photo of Piccadilly Circus

his characterisation of understandings "progressively realized and realizable through the further course of the conversation" [15:41] and the emergence of a "common scheme of interpretation and expression"[15:40].
As developed by Zimmerman [2], these ideas of the dynamic, co-production of behaviours include ad-hoc rule-breaking and rule re-interpretation in the service of pragmatic goals. Liberman [16] argued that pedestrians and vehicles concert their movements to form a local orderliness that better solved the problem than enforcing traffic rules.

3. Methods: Reading the Street, and Observing Pedestrian-Driver Interaction

In our first study, we mapped the affordances of two environments in London: Exhibition Road (Fig. 2) and Piccadilly Circus (Fig. 3). These streets were selected because they both attract mainly tourists even though the designs of the streets are different: in particular, the first is a "shared space" [17] with deliberately ill-defined zones for pedestrians and vehicles, while the second has traditional limits.

We looked at the streets in two ways: first our own analysis of the affordances of the environment, then observation of how pedestrians seemed to "read" these affordances. In the second study, we explored how pedestrians understand the intention of drivers and what kind of non-driving tasks are performed by drivers to communicate their intent. The aim was to identify the components of natural interactions between pedestrians and drivers in the chosen street environment, in order to specify the inputs which, in particular, leads pedestrians to make decisions about crossing or not crossing the street.

3.1 First Method: Reading Affordances in the Environment

Gibson used the term *affordance* [18] to capture how the physical state of an object or environment permits and encourages particular sets of interactions. A key feature of his thinking was the shift away from a nominative approach to perception - one based on naming and classifying - to a verbal one, based on action and the potential for action. Gibson's emphasis was on affordances that already exist, whereas Norman's later work shifted the emphasis to the deliberate design of visual affordances [19]. By identifying existing affordances it is possible to understand how, through design, we may be able to invite behaviours and to a certain extent predict possible interactions around a certain object. Knappett [20] describes the key elements of affordances as sociality, relationality and transparency.

To explore our two environments and users' perceptions of them, we created concept maps divided into two parts: direct perception and indirect perception. The first refers is our own observation of the properties of the environment [18]. The second captures aspects of the process of others' meaning-making in the space, by evaluating it within live social situations [20]. The framework of the map was inspired by Ferrarello at al.'s map where physical artefacts are connected by wires to labels for affordances derived from objective and subjective assessments [21]. This framework captured the differences and similarities in these two environments, showing how people use the street and interact with it. Our findings are discussed below at 4.1.

3.2 Second Method: Using Behavior Coding to Capture Interactions

We conducted live observations of street users in context for brief periods of time on multiple occasions, and coded their behaviours, using standard coding techniques [22], focusing on analyzing interaction [23]. During the observations, we periodically summarized the physical and non-verbal behaviours of the individuals in the specific categories defined in figure 4. Each code is used to mark the occurrence of a specific behaviour or set of behaviours. The result is a sequential record of the behaviours of one or more individuals.

Fig. 4. Behaviour Coding Data Sheet

Weather: Day & Time: Place:	How long they looked each other (sec.)? Who made the first move? 1.Driver 2.Pedestrian 3.Cyclist 4.Other (mention on the notes)
Age 1.(0-12) 2.(13-16) 3.(16-24) 4.(25-34) 5.(35-54) 6.(55-69) 7.(70+)	What non driving tasks driver did during the interection period?
Gender (M / F)	Crossing Diagonally
Type of User (if definable) 1.Tourist 2.Resident	Crossing at the midblock
3.Office Worker 4.Student 5.Taxi Driver 6.Uber	Crossing when there is no oncoming traffic
Driver 7.Working in Delivery 8.Uniformed Worker	Crossing when s/he sees other people cross
(number) of People	Crossing when his or her company encourages him or her
Group Description: 1.School Trip 2.Friends 3.Family 4.Couple 5.Colleagues	Encouraging his or her company to cross
Commuting Types: 1.Driving 2.Cycling 3.Pedestrian 4.Motorcyclist	Crossing mid block because shop or touristic attraction is on the other side
Who does s/he interact with? 1.Pedestrian 2.Driver 3.Cyclist Age-Gender of them	Crossing between vehicles when they stopped on the traffic
What kind of behaviour has been observed?	Crossing without paying attention to the traffic
1.Active Behaviour 2.Passive Behaviour 3.Aggressive Behaviour	Crossing while talking on the phone or listening music
Where the interaction happened? 1.Road 2.Sidewalk 3.Square 4.Crosswalk 5.Bus Stop	Crossing even there are obstacles which reduces visibility (parked vehicles, trees, buildings)
6.Traffic Light	Crossing even though there are oncoming cars
Speed Change 1.Slowed Down 2.Faster 3.Same Did they see each other? 1.P yes D no	Driver signals through gaze (1), hand gesture (2) honking (3) light (4)
2. D yes P no 3.Both of them Yes 4. None of them	Notes

The approach provides information about the frequencies of specific behaviours engaged in interactions by a certain individual. It is reasonably objective, though open to nuances of interpretation: our resources only allowed a single researcher to undertake the coding. It allows us to examine relations between behaviours, either within individuals or among pairs (pedestrian-pedestrian or pedestrian-driver). The observations help us answer questions related to social interactional processes in the street environment during the negotiations.

3.3 Group of Participants

The behaviour coding was applied to a total of 102 pedestrians (43 female, 59 male). There were 2 between age 12-16, 16 between age 16-24, 36 between age 25-34, 38 between age 35-54, 8 between age 55-70, 2 over age 70 (all ages estimated). The observations were undertaken between May and July 2018, on typical weekend days and weekdays. We coded the interactions of pedestrians during direct observation in the street according to the table in Figure 4 and took photos as needed. The data in our mappings are based on observations in the field over three days at different periods of the day at Piccadilly Circus and Exhibition Road. The most significant selection criterion was if they were involved in an interaction with another road user such as a pedestrian or driver. All the selected individuals were trying to cross the road without the aid of any form of signal or control point.

4. Findings

4.1 Findings from Affordances Mapping

Location 1, Exhibition Road, showed that people have an unusual experience of the space. As commonly with *shared space*, users have difficulty "reading" the design decisions represented by the environment. For example, not having a curb or difference of pavement height clearly leads some pedestrians to think the road is for pedestrian only, while drivers fail to identify the subtle indicators of lines and if they are going in the right lane or not. Such ambiguity has been posited as a weakness, and also as a strength of shared space on the grounds that it may cause all involved to exercise greater attention through their attempts to understand the situation [24].

When we look into Piccadilly Circus, there are some very different physical properties compared to Exhibition Road. The design of the junction more closely resembles the rest of London in terms of heights and materials. The organisation of the junction is carefully planned because it is a very crowded and busy environment. The majority of the users' age group is constituted by teenagers and young tourists,

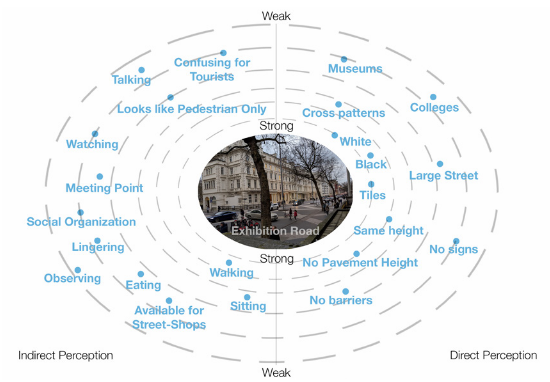

Fig. 5. Affordances Map for Exhibition Road

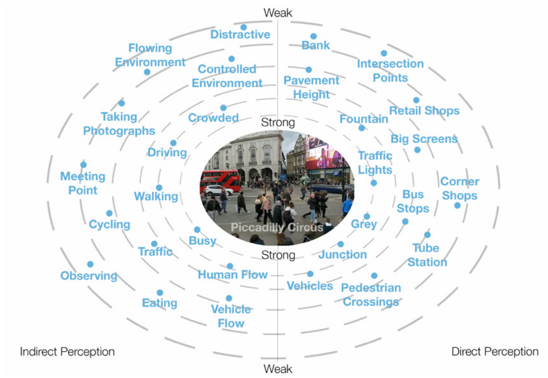

Fig. 6. Affordances Map for Piccadilly Circus

whilst Exhibition Road mainly attracts older tourists or children. The Piccadilly Circus junction is very busy because of the traffic flow at almost any time of the day, but especially at peak hours, there is a significant accumulation of car users, public transport users, cyclists and pedestrians. Illuminated high screens and neon lights for advertising create a visual distraction, potentially taking attention from the busy street environment. In addition, the number of signals to aid pedestrians is relatively low considering the complexity of the environment.

4.2 Findings from Behavior Coding:

Overall, pedestrians' actions noted were either observing other pedestrians or making eye-contact with a driver. Pedestrians' behaviours were goal-oriented, adaptive and far from automatic responses, however sometimes during the interactions with the drivers, their behaviours were built on elements which are automatized. Figure 6 summarises the key behaviour coding results for both locations for a total of 102 pedestrians (51 Exhibition Road, 51 Piccadilly Circus).

The Willingness to Interact. 85% of individuals were observed looking for signals of the drivers' intention to stop or not. They were trying to ensure that their commitment to action – to cross the road – is appropriate. Clearly, most of the people observed wanted to have feedback or respond before they acted. Throughout the interaction process, 92% of the people were able to make use of sound information; the other 7% were either listening to music or talking on their phone. 1 person out of 102 clearly had poor vision; he managed to cross the road using sound and the help of his companion.

Trust in Collective Behaviour. 42% of pedestrians who were observed planned their crossing of the road by looking at the behaviour of other pedestrians. They seem to put their trust in other pedestrians rather than relying on their own individual judgements of drivers or of the street system. This behaviour occurred mainly in Piccadilly Circus, with 34 individuals. This socially constructed engagement with traffic is a relatively neglected aspect in the literature.

Fig. 7. Results of Behaviour Coding

	Collective Behaviour	*Speed Change*	*Time Course of Interaction*
Exhibition Road	***43 out of 51*** *crossing behaviour occurred* ***individually.*** *Majority of pedestrians crossed where there are no close vehicles to themselves.*	***40 out of 51 pedestrians*** *used* ***speed*** *either as a data coming from a vehicle or as a communication tool with a driver.*	***16 out of 51 pedestrians*** *interacted with another individual for* ***maximum 5 sec.*** *and decided to cross or not to cross the road.* ***21 out of 51 pedestrians*** *interacted with another individual through eye contact for* ***5 to 10 sec*** *to make a decision.* ***14 out of 51 pedestrians*** *interacted with another individual through eye contact for* ***more than 10 sec.***
Piccadilly Circus	***34 out of 51*** *crossing behaviour occurred* ***collectively.*** *Majority of pedestrians crossed through the moving traffic.*	***33 out of 51 pedestrians*** *used* ***speed*** *either as a data coming from a vehicle or as a communication tool with a driver.*	***28 out of 51 pedestrians*** *interacted with another individual for* ***maximum 5 sec.*** *and decided to cross or not to cross the road.* ***13 out of 51 pedestrians*** *interacted with another individual for* ***5 to 10 sec.*** *and decided to cross or not to cross the road.* ***10 out of 51 pedestrians*** *interacted with another individual through eye contact for* ***more than 10 sec.***

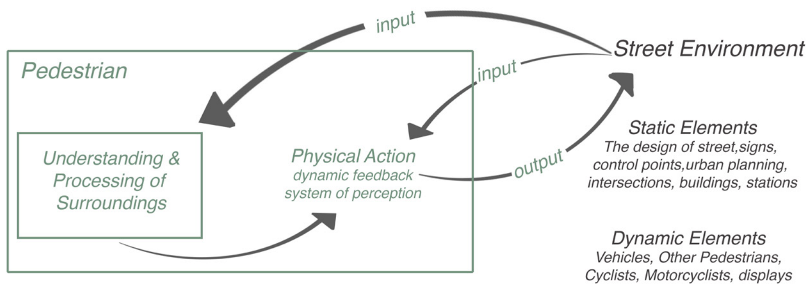

Fig. 8. Perceptual Map of Pedestrians

Negotiation through Speed Change. A majority of pedestrians used the speed of the vehicle as inputs to judge when to cross; they also negotiated with drivers through adjusting their own speed. The increase or decrease in vehicle or pedestrian speeds had a decisive effect on the negotiations between them. It was used as a means to show an intention to the other party. For 72% of individuals, this behaviour had an enacting effect on the opposite individual. For example, the driver reduces speed to allow a pedestrian to safely cross the road or the pedestrian takes a step back while trying to cross to allow the driver to pass instead. An important detail of this interaction is timing and making sure that the opposite party can read one's intention.

Time Course of Interaction. Some individuals carried out a series of actions related to the consequences of prior actions. For example, 20% of the individuals who were evidently in a hurry performed more active behaviours during the interaction period while only 18 of them performed an aggressive behaviour through sounding the horn at the pedestrian several times and making certain hand gestures. On the other hand, the results they received were fast

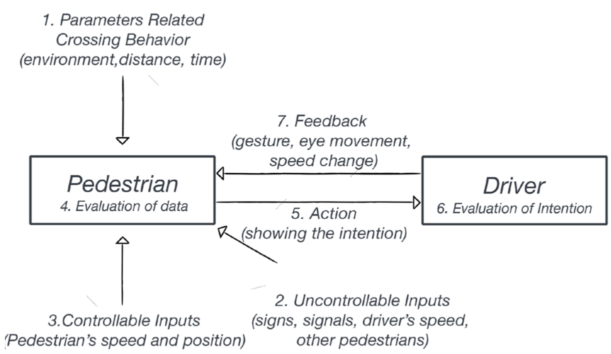

Fig. 9. The Interaction Process of Crossing Behavior

reactions. These interactions were grouped as less than 5-second interaction in Figure 6. Groups comprising families or couples showed more passive behaviour. They prioritised safety and tried to cross when there were as few vehicles as possible. Their waiting time and attention to the vehicles were noticeably higher than the rest. Drivers were more cautious towards these groups of pedestrians. The duration of interaction takes more than 10 seconds compare with individual pedestrians.

5. Discussion: Decoding The Information Flow Between the Driver and Pedestrian

The data gathered through the behaviour coding consisted of the reactions of pedestrians and drivers in two different places and their negotiation in the existing system of a street. The relationship between driver and pedestrian behaviours was observed. A conflict of interest is clearly indicated where each wishes to make progress at the expense of the other. In Figure 7 we have summarised the elements of a pedestrian's perception which affect interactions between pedestrian and driver.

The diagram captures the range of affordances that pedestrians use to interact in the street and the elements that affect their experience. Even without language or digital technology, the affordances of the environment inform pedestrians what actions are doable and preferable. This information can reframe the interaction design between autonomous vehicle and pedestrian.

In figure 8, we created a framework to informs the process of the pedestrian's interaction with the driver, and how it can be affected by the environment. This helps us to gain understanding about the pedestrian's expectation in the interaction.

We have identified how interactions occur in the traditional street environment (Figure 9) and how these might occur with autonomous vehicles (Figure 10). The diagrams show how conceiving the design task as one of constructing affordances, informing possibilities for action rather than only explicitly directing the pedestrian. This can inspire a new way to design transparent interaction between autonomous vehicle and pedestrian.

6. Limitations and Further Research

This study was part of a larger research project focused on designing a transparent framework for interaction between autonomous vehicles and pedestrians.
The framework was evaluated by participants of an exhibition using a virtual reality simulation. A future step would be to test variations of the framework through experimental tasks with a range of timings and speeds.

The study described in this paper focused on just two streets. Though different from each other as explained, they do not represent the full range of street types. It would be also helpful to use technology more extensively such as recording the selected streets for periods of time and analysing the timings, speeds and movements precisely. For instance, ethnomethodological video analysis can be considered as one of the methods as well. However, even though there are gaps that can be filled through more observation, we did acquire sufficient information to develop a new approach to designing transparency for future interactions between autonomous vehicles and pedestrians.

7. Conclusion

This study is preliminary research towards designing transparency for interactions in an urban street environment. It contributes to identifying a step-by-step approach to the decision-making process for designed transparency in interaction. In particular, it highlights the importance of feedback, the iterative perceive-act cycle, and the need for driver-vehicle system to act as a source of actionable affordances for safe action.

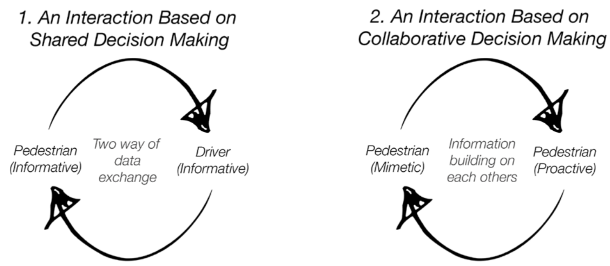

Fig. 10. Types of Interactions Occurred During The Behavior Coding

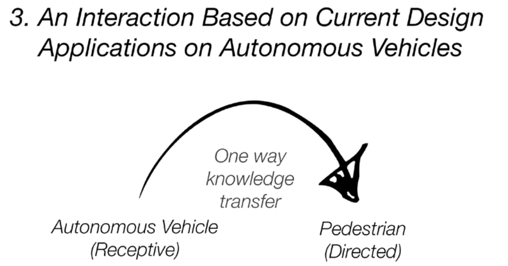

Fig. 11. The Type of Interaction Available in Current Autonomous Vehicles

As a first step, we defined what streets enable right now and what are their interactive elements. Then we looked into the interactions between actors in the same environment. These helped us to understand what is the level of transparency in the interactions happening in the street environment, what people are looking for when they need to communicate with other individuals or interact with other objects.

This qualitative research builds a case for designing interactions with autonomous vehicles by considering the street environment itself and the existing knowledge of pedestrians while taking decisions. The key findings are that the influences on pedestrians' decision-making process are: collective behaviours, subtle timings of sequenced interactions, and the use of speed as a means of communicating intention.

This research points at the opportunity of utilizing the interpersonal trust between pedestrians to help create a transparent interaction with autonomous vehicles. This can be done by triggering this kind of collective behaviour through the physical environment or the inputs of an autonomous vehicle, as well as creating a perception of collectivity in the action of an autonomous vehicle. Also, speed change and interaction time frame can be used as an input for designing interaction with autonomous vehicles. This research is presented as an invitation for future work to extend the models given.

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