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研究課題名（和文） Deep Learning Based Physiological Classifier Feedback for Comfortable Navigation

研究課題名（英文） Deep Learning Based Physiological Classifier Feedback for Comfortable Navigation

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研究成果の概要（和文）：この研究助成金は、電動車椅子（PMV; Personal Mobility Vehicle）に乗っている乗用車の快適状態検出に関する研究を行うために使用した。この研究は、乗用車による快適さの知覚を考慮に入れたナビゲーションアプローチを開発した。研究成果を利用すると、人間の快適な経路を計算し、それら安心できる速度で追跡することができます。

研究成果の学術的意義や社会的意義
This research is based on a data driven approach for safe and smooth autonomous navigation of a personal mobility vehicle (PMV) when facing pedestrians. For autonomous navigation we implemented a Frenet planner to achieve safe and smooth navigation for the passenger and pedestrians around.

研究成果の概要（英文）：This research grant was used to finance a study on multi-modal human emotional state detection while riding a powered wheelchair (PMV; Personal Mobility Vehicle). This research developed a navigational approach that takes into consideration the perception of comfort by a human passenger. Comfort is the state of being at ease and free from stress; thus, comfortable navigation is a ride that, in addition to being safe, is perceived by the passenger as being free from anxiety and stress. This study considers how to compute passenger comfortable paths. To compute such paths, passenger discomfort is studied in locations with good visibility and those with no visibility. Autonomous-navigation experiments are performed to build a map of human discomfort that is used to compute global paths. A path planner is proposed that minimizes a three-variable cost function: location discomfort cost, area visibility cost, and path length cost.

研究分野：人間情報学

キーワード：知能情報処理　知能ロボット　Human-Robot Interaction

１．研究開始当初の背景

The support ratio of the number of working-age individuals per person aged 65 or older is decreasing (2017 World Population Data Sheet). In developed countries like Japan, people being able to provide services for aged people are not enough to allow them to be independent and be engaged socially. Research institutes and companies all over the world are doing research and developing autonomous car-vehicles. On the other hand, there are few works in mobility at a smaller scale such as PMV's. PMV's can provide mobility independence between people's homes and autonomous cars or buses. Other services that could be provided by PMV's are local services such as going out for shopping or meeting friends in common spaces. In the same way, as healthy young people do, aged people like to go out independently with family or friends. People do not want to ride a semi or fully autonomous vehicle alone.

２．研究の目的

This research grant was used to finance a study on multi-modal human emotional state detection while riding a powered wheelchair (PMV; Personal Mobility Vehicle). This research developed a navigational approach that takes into consideration the perception of comfort by a human passenger. Comfort is the state of being at ease and free from stress; thus, comfortable navigation is a ride that, in addition to being safe, is perceived by the passenger as being free from anxiety and stress. This study considers how to compute passenger comfortable paths. To compute such paths, passenger discomfort is studied in locations with good visibility and those with no visibility. Autonomous-navigation experiments are performed to build a map of human discomfort that is used to compute global paths. A path planner is proposed that minimizes a three-variable cost function: location discomfort cost, area visibility cost, and path length cost. The contents of this research are divided in 2 parts:

1. Interaction Vehicle-Passenger

1.1 A study regarding comfortable navigation for the passenger based on a discomfort map
1.2 An analysis of navigational habituation during self-driving and autonomous-driving utilizing physiological sensing.

2. Comfortable Autonomous Navigation while facing other pedestrians

３．研究の方法

1. Interaction Vehicle-Passenger

1.1 Building a Passenger Discomfort Map for Autonomous Navigation

This research developed a navigational approach that takes into consideration the perception of comfort by a human passenger. Comfort is the state of being at ease and free from stress; thus, comfortable navigation is a ride that, in addition to being safe, is perceived by the passenger as being free from anxiety and stress. This study considers how to compute passenger comfortable paths. Autonomous-navigation experiments are performed to build a map of human discomfort that is used to compute global paths. A path planner is proposed that minimizes a three-variable cost function: location discomfort cost, area visibility cost, and path length.

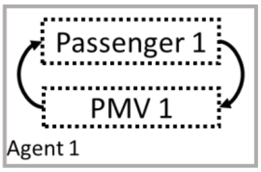


Figure 1. PMV transporting a human passenger where the ride should be safe and comfortable for the human passenger.

1.2 Navigational Habituation

The second topic of the research is regarding a model of navigational habituation for human passengers riding an autonomous robotic wheelchair. We present an example on how robot technology is utilized to understand human behavior which is useful to build human-like navigation models. The work consisted of data collection from manual driving participants, habituation modeling and autonomous navigation experimentation. Manual driving data collection consisted of recording human driving control behavior using a robotic wheelchair in a complex labyrinth-like environment, while measuring physiological activity and emotional state via subjective reports (questionnaires). The purpose of this first part was to collect a enough representation of the evolution of human driving behavior in a complex environment (23 participants), such that a numerical model could be found to approximate the trend in velocity usage; velocity usage characterizes navigational habituation.

2. Autonomous Navigation while facing other pedestrians

The second topic of the research is regarding a data driven approach for safe and smooth autonomous navigation of a personal mobility vehicle (PMV) when facing moving obstacles such as people and bicycles in public pedestrian paths. In a period of three months, data from five different persons driving the robotic PMV in an outdoor environment while facing pedestrians were collected. We performed an analysis of the parameters involved for human-driven smooth navigation. Relevant parameters regarding PMV-Human interaction included distance to moving objects, passing side and velocities. Moreover, data suggests the existence of a social navigational distance for the PWV. For autonomous navigation we implemented a Frenet planner to achieve safe and smooth navigation for the passenger and pedestrians around.

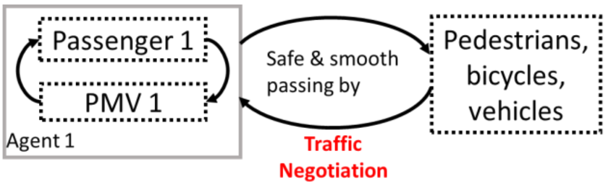


Figure 5. A PMV transporting a human passenger while negotiating traffic with pedestrians.

４．研究成果

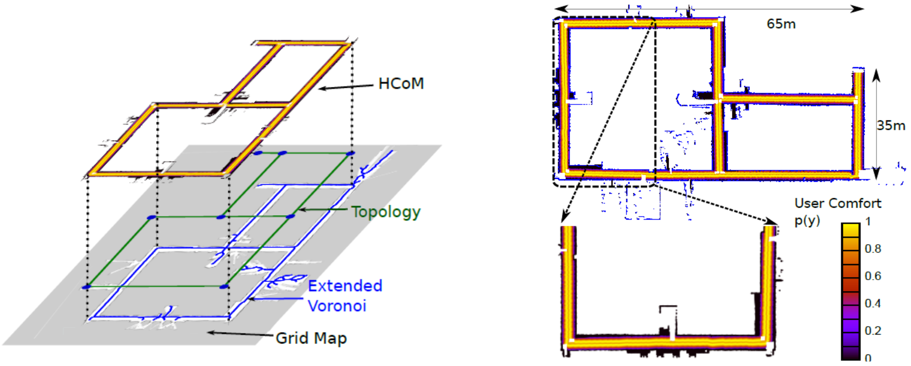
1.1 Building a Passenger Discomfort Map for Autonomous Navigation

Based on data extracted from human passenger experimentation, modeling the corridor location comfort is given by eq. (1) where y is the normalized position within the corridor ($0 < y < 1$) and constant c is the preferred position in the corridor. For model generalization, variable y and constant c are given in the corridor with values between 0 and 1. The other constants are defined as $a = 0.1$ and $b = 0.3$.

$$U(y) = \frac{a}{y} + \frac{a}{1-y} + \left(\frac{y-c}{b}\right)^2$$

$$p(y) = e^{-U(y)} \qquad (1)$$

The process for computing the discomfort map (HCoM) is illustrated in Fig. 2. Firstly, we extracted the nodes and edges of the grid map (bottom layer) that builds an extended Voronoi graph (bottom layer). The topology was simplified with straight line segments because the standard Voronoi graph is sensitive to irregularities in the environment produced by sensor noise or irregular surfaces, which would result in irregular cost maps for the HCoM. The final graph is illustrated in the center of Fig. 2.a, where nodes of the graph are illustrated in blue and edges in green. Finally, we assigned the width of the corridor (2.4 m) to all segments and applied the model in Eq. 1 to obtain HCoM.

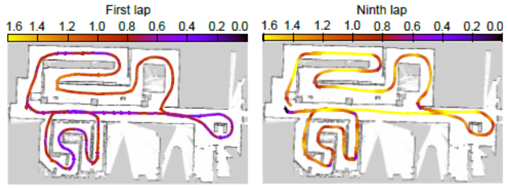


a) From bottom to top: occupancy grid map, the extended Voronoi graph, topological map and on top the Human-Comfort Map (HCoM).

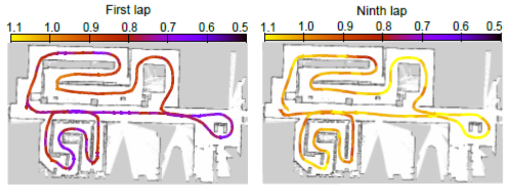
b) Most comfortable locations are shown in yellow; the darker the color, the less comfortable

Figure 2. Mapping navigational discomfort in visible areas on top of a geometric map.

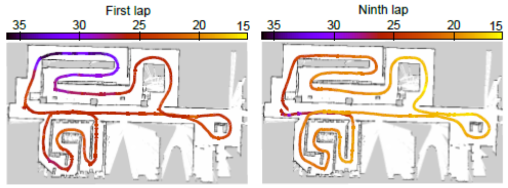
1.2 Navigational Habituation



(a) Driving velocity in m/sec. Velocity was slower in the first lap compared to the ninth lap.



(b) Heart inter-beat interval (IBI) in *s*. IBI was lower showing more arousal in the first lap compared to the ninth lap.



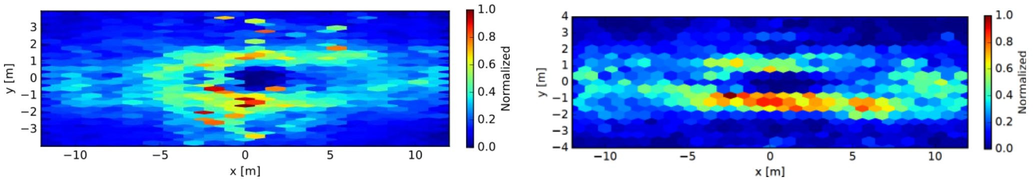
(c) Galvanic skin response in *microSiemens*. GSR response showed higher absolute values compared to the one's in the ninth lap.

Fig. 4. Comparison of vehicle velocity and physiological measurements of a human driving a course. The first lap is on the left and the ninth lap on the right.

Fig. 4 shows an example of navigational habituation. The figure shows a participant driving a robotic wheelchair in a labyrinth-like environment for nine laps. The left side of the figure shows the first driving lap and the right side shows the ninth driving lap of the same driver. The top shows vehicle velocity (in m=sec), the middle row shows driver IBI (in sec) and the bottom row shows the driver skin conductance (in microsiemens) It can be seen that on the first lap (left side), velocity is low, heart beat is low (meaning high beating frequency) and galvanic skin conductance response is high. This means that despite the human drives at slow velocities his emotional sate arousal level is high. The ninth lap of the driver is shown on the right side. As the driver became habituated, the driving velocity became higher (Fig. 4(a)). Despite driving faster, inter-beat interval became higher (lower heart frequency rate) (in Fig. 4(b)) and his galvanic skin response went down (Fig. 4(c)).

2. Autonomous Navigation while facing other pedestrians

We built personal space distribution graphs for autonomous navigation. In Fig. 6.a. red color means high density and dark blue low density. Around (0,0) there is a sort of navigational personal space where pedestrians did not enter. This ellipsoidal shape which extend up to around 3.5 m is similar to what has been reported in personal space literature. As it is hard to visualize the interactions in this density graph, we picked up by hand and analyzed some typical interactions such as passing by facing pedestrians, following, leading and side by side. As it is hard to visualize the interactions in this density graph, we picked up by hand and analyzed some typical interactions such as passing by.



(a) Distribution of PMV driven along people (b) PMV passing by pedestrians.

Fig. 6 Human driven data. PMV navigating through pedestrian flow.

Our planner gave preference towards avoiding left, nevertheless, as shown in experimental result figure 7 our experimental environment is complex and there are people coming at both sides of the road. The snapshots figure shows the cluttered target environment.

Fig. 7. On the left, the PMV first avoided a girl walking on the right side of the sidewalk after she avoided some bicycles. Then the PMV had to move back left to avoid incoming

pedestrians. On the right the wheelchair avoids the man crossing the road while there is a bicycle coming on the right. Then there is a man in suit walking on the left.

５．主な発表論文等

〔雑誌論文〕（計　　１件）

1) “Passenger Discomfort Map for Autonomous Navigation in a Robotic Wheelchair”

Morales Y., Watanabe A., Ferreri F., Even J., Shinozawa K., Hagita N.

Robotics and Autonomous Systems Journal. February 2018 [査読有]

〔学会発表〕（計　　５件）

1) Safety Criteria Investigation During Passing Blind Corners Based on Driver's Attention Simulation in 3D Map for PMVs

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Submitted to ITSC 2019　[査読有] (投稿中)

2) Pedestrian Density Prediction for Efficient Mobile Robot Exploration

Zapf M.P., **Morales Y.** and Kawanabe M.

Submitted to IROS 2019　[査読有] (投稿中)

3) **Morales Y.**, Akai N., Hirayama T., and Murase H.

Towards Social Mobility: Shared Planning for Multiple Personal Mobility Vehicles

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4) Personal Mobility Vehicle Autonomous Navigation through Pedestrian Flow: A Data Driven Approach for Parameter Extraction

Morales Y., Akai N., and Murase H.

IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2018) [査読有]

5) Data-Driven, 3-D Classification of Person-Object Relationships and Semantic Context Clustering for Robotics and AI Applications

Zapf M.P., Gupta A., **Morales Y.** and Kawanabe M.

RO-MAN 2018　[査読有]

6) Analysis of Navigational Habituation

Morales Y., Even J., Abdur-Rahim J.

IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2017) [査読有]

〔図書〕（計　　０件）

〔産業財産権〕

○出願状況（計　０　件）

○取得状況（計　０件）

６．研究組織