ROBOTIC NAVIGATION AID FOR VISUALLY IMPAIRED PEOPLE USING FLC-ORCA

BY

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ABSTRACT

Robotic Navigation Aid (RNA) provides an option for visually impaired people for self-navigation and allow them to travel independently. However, current research does not take into consideration the varying characteristics and different states of obstacle which is present in the surrounding. Current methods of obstacle avoidance have been one-dimensional and limited in terms of representing the real-life surrounding when it comes to simulation and experimental conduct. Navigations are done either within a confined space of clear path, passing through static objects or between other mobile robots itself. Dynamic obstacles are presented within a controlled manner without differentiating class of objects which is intelligent and have the ability to avoid obstacles by itself. While separating static and dynamic objects are clear-cut and obvious, the same could not be said about differentiating moving object and intelligent entity with unpredictable movement. Moreover, the obstacle avoidance methods which attempt to solve the problem of collision within varying state of obstacles tend to assume that other intelligent entity follows the same obstacle avoidance protocol as itself. Furthermore, the presupposition that other intelligent entity bears equal liability of collision avoidance are too far from the circumstances faced in real life. Hence, the introduction of novel methodologies of CE-CBCE & FLC-ORCA attempts to fill in the void within two correlated and fundamental fields of object detection and obstacle avoidance. The proposed CE-CBCE feature extraction method detects human, cyclist and vehicles and separates it from other moving object to be classified as intelligent entity. Sequentially, FLC-ORCA resolves the issue of diversified position, velocity, acceleration, and density of obstacles and depicts the output of responsibility to avoid collision and predicts the obstacle character in the next cycle of scanning. The CE-CBCE feature extraction method recorded 97% detection and classification when tested using 1200 dataset consist of human, motorcyclist and vehicle point cloud data. The method is then tested with higher difficulty experiment, where it is required to recognize the class of the object and at the same time to determine the object's pose detection. Impressively, the proposed CE-CBCE yields 82% of accuracy. Final experiments conducted within a living room environment with the presence of static obstacles, human as the intelligent entity and mobile robot TurtleBot 3 as rigid dynamic object moving without collision avoidance liability. Navigations are observed and its time of navigation, rerouting occurrence, change of heading angle, occurrence of stoppage and time of stoppage are recorded. Final results exhibit that the proposed FLC-ORCA method outperforms other state-of-the-art obstacle avoidance methods. Based on the experiment conducted, it can be inferred that the proposed FLC-ORCA allows navigation within static, dynamic and intelligent entity obstacles. It also prevails in avoiding collision within moving object with different collision avoidance protocol and different liability to circumvent obstruction. With the proposed method of CE-CBCE and FLC-ORCA, the risk of accidents and collision within the visually impaired people could be prevented. Therefore, allowing them to be independent while successfully achieving self-navigation in a safe, secure and unharmed manner.

ملخص البحث

يوفر مساعد التنقل الآلي خيارًا للأشخاص المعاقين بصريًا للتنقل والسفر الذاتي والمستقل. ومع ذلك ، فإن البحث الحالي يتجاهل الخصائص المتغيرة والحالات المختلفة للعائق الموجود في المحيط. وبشكل أكثر تحديدًا ، عدم التطرق إلى تصنيف العائق بشكل صحيح إلى كيان ثابت وديناميكي وذكي. تتم عمليات التنقل إما داخل مساحة ضيقة من مسار واضح ، أو بالمرور عبر كائنات ثابتة أو بين الروبوتات المتنقلة الأخرى نفسها. العوائق الديناميكية حاضرة في طريقة مضبوطة دون تمييز فئة الأشياء والتي هي ذكية ولديها القدرة على تجنب العوائق تلقاء نفسها. على الرغم أن في بعض المولفات الحديثة، تم ضم كيانات ذكية في التجارب، بينما طبيعتها ، مع الاختلاف في الخصائص وحالات التعاون المتغيرة عندما تصادف كائنات أخرى لم يتم تسليط الضوء عليها بشكل كافٍ. علاوة على ذلك ، تميل طرق تجنب العوائق التي تحاول حل مشكلة الاصطدام ضمن العوائق متغيرة الحال إلى افتراض أن الكيان الذكي الآخر يتبع نفس بروتوكول تجنب العوائق مثلها.علاوة على ذلك ، فإن الافتراض المسبق بأن الكيانات الذكيه الأخرى تتحمل مسؤولية متساوية في تجنب الاصطدام بعيد جدًا عن الظروف التي نواجهها في الحياة الواقعية. لذلك ، فإن تقديم منهجيات جديدة لـ CE-CBCE و FLC-ORCA تحاول ملء الفراغ ضمن مجالين مترابطين وأساسيين لاكتشاف الأشياء وتجنب العوائق. الطريقة المقترحة CE-CBCE لاستخراج الخصائص تكتشف الإنسان وراكبي الدراجات والمركبات وتفصلها عن الأشياء المتحركة الأخرى لتصنيفها على ككيان ذكي. بالتعاقب ، يحل FLC-ORCA إشكالية تنوع المكان والسرعة والتسارع وكثافة العوائق ويصور ناتج المسؤولية لتجنب الاصطدام ويتنبأ بسلوك العائق في الدورة التالية من المسح. سجلت طريقة استخراج الخاصية CE-CBCE اكتشافًا وتصنيفًا بنسبة 97 ٪ عند تم اختبارها باستخدام مجموعة بيانية سحابية مكونة من 1200 بيان مسجل للإنسان وراكب الدراجة النارية وللمركبة. تم اختبار الطريقة في تجربة ذات صعوبة أعلى ، حيث يلزم التعرف على فئة الكائن وفي نفس الوقت تحديد اكتشاف وضع الكائن. بشكل مثير للإعجاب ، المقترح CE-CBCE ينتج 82٪ من الدقة. أجريت التجارب النهائية داخل بيئة غرفة المعيشة مع وجود عوائق ثابتة وكذا الإنسان ككيان ذكي وايضا روبوت المتحرك TurtleBot 3 ككائن ديناميكي صلب يتحرك دون مسؤولية تجنب الاصطدام. تم ملاحظة عمليات التنقل وتسجيل كلا من وقت التنقل وحدوث إعادة التوجيه وتغيير زاوية التوجه ووقوع التوقف ووقت التوقف. النتائج النهائية تظهر أن الطريقة المقترحة FLC-ORCA تتفوق على طرق تجنب العوائق الأخرى. بناءً على التجربة التي تم إجراؤها ، يمكن الاستدلال على أن المقترح FLC-ORCA يسمح بالتنقل بين العوائق والكيانات الثابتة والديناميكية والذكية. كما أنه يسود في تجنب الاصطدام مع جسم متحرك ببروتوكول تجنب اصطدام مختلف ومسؤولية مختلفة للالتفاف على العوائق. من خلال الطريقة المقترحة لـ CE-CBCE و FLC-ORCA ، يمكن منع حوادث الاصطدام بين الأشخاص المعاقين بصريًا. لذا ، السماح لهم بالاستقلالية في تحقيق التنقل الذاتي وأمان وبعيدا عن الأذى.

APPROVAL PAGES

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I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions

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الْحَمْدُ لِلَّهِ الَّذِى بِنِعْمَتِهِ تَتِمُّ الصَّالِحَاتُ

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LIST OF ABBREVIATIONS

ETA	Electronic Travel Aid
RNA	Robotic Navigation Aid
CE	Clustered Extraction
CBCE	Centroid Based Clustered Extraction Method
FLC	Fuzzy Logic Controller
ORCA	Optimal Reciprocal Collision Avoidance
FLC-ORCA	Fuzzy Logic Controller-Optimal Reciprocal Collision Avoidance
GUI	Graphic User Interface
LiDAR	Light Detection and Ranging
AI	Artificial Intelligence
k-NN	k-Nearest Neighbour
DT	Decision Tree
CNN	Convolutional Neural Network
EEG	Electroencephalography
EM	Electromagnetic
VNA	Vector Network Analyzer
TSM-KF	Time-Stamped Map Kalman Filter
IR	Infrared
VFH	Vector Field Histogram
VGA	Video Graphic Array
IMU	Inertial Measurement Unit
SVM	Support Vector Machine
HOG	Histogram of Oriented Gradient
FPFH	Fast Point Feature Histogram
GNSS	Global Navigation Satellite System
MLS	Mobile LiDAR Scanning

ALS	Airborne LiDAR Scanning
MFE	Multiple Feature Extraction
FV	Feature Vector
ROI	Region of Interest
DM	Depth Map
RANSAC	Random Sample Consensus
ECE	Extended Collinear Equations
FL	Fuzzy Logic
OF	Optical Flow
SFLC	Same Fuzzy Logic Controller
CLMR	Car Like Mobile Robot
DDQN	Double Deep Q Network
BNN	Behaviour-based Neural Network
RNN	Recursive Neural Network
RNNC	Recursive Neural Network Controller
PWM	Pulse Width Modulation
MIMO	Multi-Input Multi-Output
DRL	Deep Reinforcement Learning
MDRLAT	Multimodal DRL Auxiliary Task
MFB	Modified Frequency Bat
PSO-MAB	Particle Swarm Optimization-Modified Frequency Bat
LS	Least Square
APF	Artificial Potential Field
DWA	Dynamic Window Approach
PSO	Particle Swarm Optimization
FNN	Feedforward Neural Network
MPR	Mobile Parallel Robot
GA	Genetic Algorithm
RVO	Reciprocal Velocity Obstacle

VO	Velocity Obstacle
DORCA	Directional Optimal Reciprocal Collision Avoidance
VR-ORCA	Variable Responsibility Optimal Reciprocal Collision Avoidance
RF	Radio Frequency
IDE	Integrated Development Environment
SBC	Single-Board Computer
ROS	Robot Operating Software

LIST OF SYMBOLS

$VO_{A\|B}^{\tau}$	Set of all relative velocities of A with respect to B
$CA_{A\|B}^{\tau}(V_B)$	Collision avoiding velocities for A given that B selects its velocity from V_B
$ORCA_{A\|B}^{\tau}$	Reciprocal collision avoidance velocity set
$\mathbf{u}$	Smallest change required to avert collision in τ time frame
$\boldsymbol{v}_A^{new}$	New velocity
$\boldsymbol{v}_A^{pref}$	Preferred velocity
$\boldsymbol{p}_A^{new}$	New position
n_d	Smallest change for relative velocity vector to avoid collision
N_{AB}	Common neighbour
γ	Safety weight balancing
$P_{A\|B}$	Distance between new velocity and its current velocity
$G_{A\|B}$	Maximum signed distance.
P	Clustered LiDAR point cloud data
w	Width
l	Length
h	Height
N	Number of points
α	Values of width, length, height and points
β	Number of elements within the segregated intervals
γ	Minimum and maximum value of each axis in the clusters
$x_{dataset}$	Element within x axis
$y_{dataset}$	Element within y axis

$z_{dataset}$	Element within z axis
x_{min}	Minimum x value
x_{max}	Maximum x value
y_{min}	Minimum y value
y_{max}	Maximum y value
z_{min}	Minimum z value
z_{max}	Maximum z value
c	Centroid
x_{floor}	x floor value
$x_{ceiling}$	x ceiling value
y_{floor}	y floor value
$y_{ceiling}$	y ceiling value
z_{floor}	z floor value
$z_{ceiling}$	z ceiling value
δ	Features related to density to centroid height ratio
ρ/h	Density to centroid height ratio
ε	Features related to density to volume ratio
ρ/V	Density to volume ratio
n_i^h	Height of cluster
ρ_i^{diff}	Density between interval
ρ_i^c	Current cluster density
ρ_{i-1}^c	Previous cluster density
V_i^{diff}	Volume difference
V_i^c	Current cluster volume
V_{i-1}^c	Previous cluster volume
TP_i	True positive

TN_i	True negative
FP_i	False positive
FN_i	False negative
$\boldsymbol{D}$	Centroid of the combined shape,
$\boldsymbol{A_i}$	Individual areas
$\boldsymbol{C_i}$	Individual centroids.
d	Distance of the obstacle
v	Velocity
a	Deceleration
u	Avoidance responsibility
ρ	Density
$\bar{v}$	Predicted velocity
v_B^{pref}	Output expected velocity

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

For visually impaired people, the most common navigation aid is white canes. While this gives an excellent solution for a near ground obstacle, uneven surfaces lower than the ground or obstacles higher than knee level remain undetected. Difficult circumstances such as moving within a crowd, hanging tree branches and potholes might also cause problems to visually impaired people. Hence, researchers are keen to explore scientific advancements which could help the visually impaired community with self-navigating. Mobility aids for visually impaired people known as Electronic Travel Aids (ETAs) are equipped with measurement systems to detect objects and avoid collision (Roijezon et al., 2019). Some of the objectives and challenges of ETA includes detection of obstacle, information on the travel surface, location of landmarks, identification information, self-familiarization and mapping of the surrounding (Cardillo and Caddemi, 2019). Through solid ETA construction, the visually impaired people can be more self-independent, less likely to be involved in accidents, improve their reachability and finally improve the living lifestyle. The objective would be to enable the visually impaired people to travel in a safe and secure condition.

In general, ETAs for the visually impaired person can be classified into three categories viz., Robotic Navigation Aids (RNA), wearable attachments and smartphone-based system (Ogawa et al., 2014). RNA or also known as robotic guide dog is a type of machinery that carries themselves. Usually in the form of wheeled robot, it possesses simpler dynamics and mechanical necessity. An active RNA moves on its own, preventing the user from fatigue and decreases burden. However, safety remains as the main issue as the user completely depends on RNA for navigation. As image processing and video processing are gaining popularity nowadays, some researchers opted for a smartphone-based assistive system for visually impaired. Custom applications, maps with the Graphic User Interface (GUI) and image processing are some of the examples of smartphone usage in this category. Meanwhile, wearable attachment to the body includes various design, targeting different parts of the body for device fitting.

Based on Table 1, there are advantages and disadvantages for each type of ETAs. Depending on the target user, researcher can choose which design will benefit best for their target subject. In this research, for navigation system to aid visually impaired person without physical limitation, we chose mobile robot type for the design. There are room for sensor selection unlike mobile phone systems, and it would not be invasive or require extensive training as like wearable attachment system. With flexible design possibilities, it can fulfil the requirement of obstacle recognition, obstacle avoidance and navigation for visually impaired person to be independent and self-reliance.

Table 1.1 Advantages and disadvantages of varying ETAs

Type of ETAs	**Implementation**	**Advantages**	**Disadvantages**	**Ref**
Robotic Navigation Aids	Smart cane	– Portable – Converted into a normal white cane if the electronics cease to function.	–Needs to be compact and lightweight –Lacks obstacle information because of restricted sensing ability offers little information on wayfinding and navigation purposes as it requires bigger and bulkier hardware	(Ogawa et al., 2014; Ye et al., 2016)

	Robotic guide dog/ mobile robot	– The system gives room for larger hardware, as it does not require a user to carry it	–Complicated mechanicals while manoeuvring through stairs and terrain	(Ogawa et al., 2014)
	Robotic wheelchair	– Suitable for the elderly and people who have a physical limitation provides navigation and mobility assistance for elderly visually impaired who cannot walk on their own, multi-handicapped, or people who have more than one disabling condition	–Safety remains an issue as user mobility fully depends on the robotic wheelchair navigation, road-crossing and stair climbing are difficult circumstances where the reliability of the wheelchair is of extreme necessity	(Ye et al., 2016)
Smartphone Based System	-Android apps -Maps -Image Processing	–Mobility/portability – No load or – Not invasive to the user	–The system depends on sensors available on the smartphone. -May communicate with an outer sensor such as beacon or external server but then it limits the usage for indoor requires certain orientation for image processing or internet signal for online maps	(Pissaloux, Velázquez and Maingreaud, 2017)
Wearable attachment	Eyeglass	– Gives a natural appearance to the visually impaired user when navigating outdoors	–Too much attention is required, thus giving a cognitive load to the user – Devices are intrusive as sometimes it covers their ears or attached on their hands – Users are burdened with the system's weight. – Requires a long period of training.	(Bahadir, Koncar and Kalaoglu, 2012; Ogawa et al., 2014)

Object recognition is an integral part of robotics (Wang et al., 2017, 2019; Asvadi et al., 2018; Li, Chen and Shen, 2019), and it is commonly depending on feature extraction for object classifications. Accurate classification and object detection enables object tracking, road signs detection, scene understanding (Xu et al., 2019) and behaviour recognition (Li et al., 2020). 3D-Light Detection and Ranging (LiDAR) traits based on local surface and key-points are amongst the main features for extraction within object recognition (Guo et al., 2014). These key-point detection algorithms extract normal vector, curvature, variances or any other spatial geometric attributes as its feature extraction objectives. These key-points are identified for matches between newly detected object and predicted object following the transformation phase.

In order to provide visually impaired people with save journey to their destination, one of the most important aspect is to ensure collision-free navigation. It is also a