Real time hand gesture detection by using convolutional neural network for in-vehicle infortainment systems

Wan Mohd Yaakob Wan Bejuri[1], Siti Azira Asmai[1], Raja Rina Raja Ikram[1], Nur Raidah Rahim[1], Najwan Khambari[1], Mohd Sanusi Azmi[1], Yus Sholva[2]
[1]Fakulti Teknologi Maklumat dan Komunikasi, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Malaysia
[2]Fakultas Teknik, Universitas Tangjungpura, Pontianak, Indonesia

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ABSTRACT

Nowadays, a variety of technologies on autonomous vehicles have been extensively developed, including in-vehicle infotainment (IVI). It have been noted as one of the key services in the automobile industry. In the near future, people will be able to watch some virtual reality (VR) movies through the streaming service provided in the vehicle. However, a person sometime not tend to be joy while watching espcially when the remote controller or audio sensory controller lack of battery or too far from IVI panel. Thus, the purpose of this research is to design a scheme of real time hand gesture detection for in-vehicle infotainment system, in order to create human computer experience. In this research, the image of human palm hand will be taken by using camera for recognize the hand gesture action. This proposed scheme will recognize human gesture and convert to be computer intruction, that can be understood by IVI device. As a result, it show our proposed scheme can be the most consistent in term of accuracy and loss compared to others method. Overall, this research represents a significant step toward improving better user experience. Furthermore, the proposed scheme is anticipated to contribute significantly to the IVI field, benefiting both academia and societal outcomes.

Corresponding Author:

Wan Mohd Yaakob Wan Bejuri
Fakulti Teknologi Maklumat dan Komunikasi, Universiti Teknikal Malaysia Melaka
Durian Tunggal, Malaysia
Email: yaakob@utem.edu.my

1. INTRODUCTION

In-vehicle infotainment (IVI) systems represent a sophisticated integration of various vehicular functions into a unified, screen-based interface, offering users essential information and entertainment features [1]-[10]. These systems typically consolidate multiple secondary functions of the vehicle into a single, accessible display, prominently positioned on the vehicle's front panel. By leveraging a combination of sensory input mechanisms and processing subsystems, IVI systems are designed to enhance the driving experience through interactive capabilities. This involving such as remote controls, touchscreens, and voice commands. The main purpose of IVI system basically is to facilitate effective user interaction by converting commands or safety camera signal into actionable data, which is then processed and stored in a central data repository [11]-[15]. Thus, improving the user experience of IVI systems is crucial for particularly during extended journeys. A well-designed system also can significantly contribute to driver comfort and satisfaction [16]-[21]. Despite the significant advancements have been made in previous studies [21]-[23], the primary focus has often been on touchscreen user experience which overlooking the broader aspects of user interaction that are essential for optimizing in-vehicle infotainment systems. In this paper, we aim to design a real-time hand gesture recognition scheme within the IVI environment. This framework comprises two key components which are detection and command execution. It is identifies and interprets distinct hand shapes in real-time and enabling various commands execution. This is invoving such as play, pause, or volume adjustment. This approach not only enhances passenger enjoyment particularly during long drives, but also improves overall human-computer interaction within the vehicle and the same time providing a comprehensive and user-friendly IVI experience. This paper is structured as follows; Section 2 presents the proposed method. Section 3 presents the results and discussion of the proposed method, while section 4 concludes with recommendations for future research and potential improvements to the system.

2. REALTIME HAND GESTURE DETECTION

Many research explore the suitability of the input device for interactive entertainment with a focus on usability, user engagement, and personal motion control sensitivity. Basically, it is based on three established interaction modalities such as, remote controls, touch screens, and voice commands. Firstly is remote controls, it is providing a tactile and familiar interface. However, it is constrained by issues such as limited battery life and the physical reach required to operate them. It is potentially diminishing their usability [22]-[26]. Second is touch screens, it have emerged as a prevalent alternative by offering a dynamic and intuitive interface which supports multi-touch gestures. However, their integration into IVI systems has introduced concerns of driver distraction and the challenge of maintaining usability under driving conditions [27]-[29]. Lastly is voice control systems. It is facilitate hands-free operation and represent a significant advancement by reducing physical interaction; nonetheless. They grapple with challenges related to speech recognition accuracy and the interference of ambient noise [30]-[33]. The field is now witnessing a burgeoning interest in hand gesture recognition as a novel interaction paradigm. This emerging approach promises to overcome the limitations of existing control methods by providing a more intuitive and seamless mode of interaction. In this research, as mentioned before, we aim to design a scheme of real time hand gesture detection for in-vehicle infotainment system, in order to create human computer experience. According to this Figure 1, it is outlines a system flow of developing and deploying a machine learning model within a web application. It is beginning with gesture recognition phase and a command execution phase. The gesture recognition module processes these images using advanced computer vision and machine learning techniques. It is including feature extraction methods like histogram of oriented gradients (HOG) and convolutional neural networks (CNNs) which is accurately classify hand gestures. Once a gesture is recognized, the command execution module translates it into specific IVI system commands such as navigating a playlist or adjusting volume. The system is optimized for real-time processing with minimal latency by using lightweight models and dedicated computing resources like GPUs. Rigorous evaluation and validation will be conducted to ensure robustness and high performance under varying conditions. It is including different lighting, hand sizes, and backgrounds. The proposed method addresses potential challenges, such as varying environmental conditions and passenger movements through adaptive algorithms and dynamic feedback mechanisms. This approach offers a significant advancement in IVI systems by enhancing human-computer interaction and ultimately improving the overall user experience in autonomous vehicles.

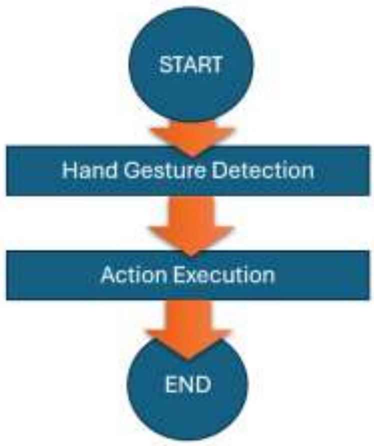

Figure 1. The overview of entire scheme

2.1. Hand gesture detection

The proposed method for hand gesture detection in IVI systems employs a CNN, specifically the VGG-16 architecture. It is to recognize and classify hand gestures in real time. The process begins with the image acquisition module which captures images of the user's hand using a high-resolution camera positioned within the vehicle cabin. These images are preprocessed to standardize input dimensions typically resizing to 224 x 224 pixels and normalizing pixel values to enhance model performance. The VGG-16 network consists of 13 convolutional layers with small 3 x 3 filters and three fully connected layers, designed to extract hierarchical features from the input images. The convolution operation, mathematically defined as (1):

$$(I * K)(x, y) = \sum_{i=-m}^{m} \sum_{j=-n}^{n} I(x + i, y + j). K\ (i, j) \quad (1)$$

where $I(x, y)$ is the input image, $K(i, j)$ is the kernel (filter) matrix and m (is used to detect edges, textures, and patterns corresponding to different hand gestures. The activation function Rectified Linear Unit (ReLU) defined as (2).

$$ReLU(z) = max(0, z) \quad (2)$$

It is introduces non-linearity by allowing the model to learn complex patterns (where z is the output from the convolutional layer). The output from the final convolutional layer is flattened and fed into fully connected layers where the softmax function converts the logits into probabilities as (3).

$$P(y = c|x) = \frac{e^{zc}}{\sum_{j=1}^{C} e^{zj}} \quad (3)$$

This is to classify the gestures. The model is trained using a large dataset of hand gesture images to minimize the cross-entropy loss. The optimization is performed using algorithms like stochastic gradient descent (SGD). This approach ensures high accuracy and efficiency in recognizing hand gestures thereby enhancing user interaction with IVI systems by providing a natural, intuitive interface for controlling in-vehicle functionalities without relying on traditional input devices.

2.2. Action execution

The Action recognition phase translates detected hand gestures into actionable commands for IVI systems, such as "Play," "Pause," "Stop," "Volume Up," "Volume Down," and "Mute." After hand gestures are classified by the CNN using VGG-16, the system maps each gesture to a specific control action based on predefined mappings. For instance, a "Swipe Right" might correspond to "Play," while a "Pinch Out" could trigger "Volume Up." This mapping process ensures that each recognized gesture is accurately associated with the correct command, which is then executed by interfacing with the IVI system's API. The command execution is carried out in real-time by providing immediate feedback, such as visual or auditory cues. This is to confirm that the action has been performed. The system's effectiveness is evaluated through user testing by focusing on metrics like recognition accuracy, response time, and overall user satisfaction. The adjustments made as necessary to enhance performance and user experience. This phase is crucial for creating an intuitive and efficient interface that allows users to control IVI functions through simple hand gestures.

3. RESULTS AND DISCUSSION

This section outlines the findings of our study and presents a detailed discussion. For our implementation, we utilized Microsoft Visual Studio and Jupyter Notebook as our coding environments. The libraries employed include Anaconda Navigator, TensorFlow, Flask, Keras, and additional libraries such as OpenCV2 and Keyboard for API functionalities. The subsequent sections will be divided into two subsections, data acquisition and test results with analysis.

3.1. Data acquisition

This subsection describes the methodology for preparing the experimental data. The data and related information were sourced from online repositories specifically the Jester dataset. It is focuses on gesture recognition (refer to Figure 2 for a sample dataset). The dataset was obtained through web scraping from the Jester website for ensuring data integrity. It encompasses a variety of gesture classes including sliding down, swiping left, drumming fingers, swiping right, thumb up, sliding fingers up, among others. Each class is assigned a specific number of training samples and the training is conducted according to these predefined classes. Upon setting up the environment, the RESNET model was trained using the prepared dataset and its performance was evaluated through accuracy and loss graphs. The video labels were extracted from the data frame and dictionaries were created to map labels to integer values and vice versa. These data dictionaries facilitate the conversion between index numbers and their corresponding class names.

Figure 2. The dataset

3.2. System implementation and testing

In this subsection, the result of the our proposed scheme will be showed. It showed system completely done by referring to Figure 3. After done some activation command by using hand gesture, it can pause, play or do other task such increasing volume and decreasing volume. In order verify whether the system can be used in real environment, the test acceptance has been conducted. The acceptance will done through twenty (20) user. By referring to Table 1, it displays the test results and analysis from each end-user for each test cycle as well as their satisfaction. From there, it is clearly show all the user statisfy with the implementation of the system.

Table 1. Test result and analysis for each end-user

System	Users	Test cycle	Result	Satisfication
Manual implementation	Project Admin	1	SUCCESS	SATISFIED
		2		
		3		
Web application system	End-User	1	SUCCESS	SATISFIED
		2		
		3		
	End User	1	SUCCESS	SATISFIED
		2		
		3		

Figure 3. Activation command by hand gesture

3.3. Performance evaluation

The performance evaluation of the gesture recognition models; RESNET, VGG-16, and VGG-19 as shown in Figure 4. Basically, it was conducted by training each model for 50 epochs with 200 steps per epoch and followed by validation over 5000 steps. The accuracy performance graphs indicate that the RESNET model achieved rapid learning and reaching near perfect training accuracy but its test accuracy stabilized around 0.8. This suggests that while RESNET effectively learns from the training data, it may be prone to overfitting as evidenced by its reduced generalization ability on unseen data. Conversely, the VGG-16 model demonstrated a more balanced performance with a test accuracy of approximately 0.9 that closely mirrored its training accuracy. This alignment indicates that VGG-16 has superior generalization capabilities and is less affected by overfitting compared to RESNET. The VGG-19 model exhibited a slower convergence rate with training and test accuracies plateauing around 0.75 and 0.7 respectively. This slower learning curve might reflect a more gradual but potentially more robust generalization in earlier epochs. The VGG-16 model emerged as the most effective in terms of balancing learning efficiency and generalization making it the preferred choice for this dataset. As the end, future research should explore advanced regularization techniques and data augmentation methods. These improvements could enhance model robustness and performance across diverse real-world scenarios. This is to address the overfitting observed in RESNET and improve the convergence speed of VGG-19 as overall.

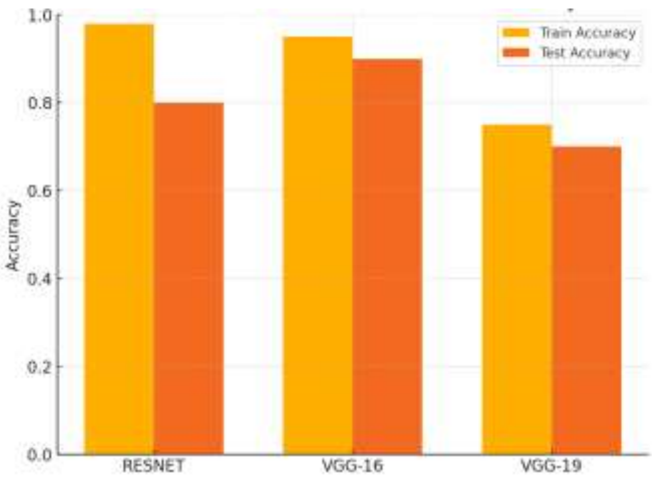

Figure 4. Model train and test comprison

4. CONCLUSION

This paper presents a novel approach to enhancing IVI systems through a real-time hand gesture recognition scheme. IVI systems, which integrate various vehicle functions into a unified screen-based interface, are pivotal in improving user comfort and satisfaction during vehicle operation. Traditional methods of interaction, including touchscreens, remote controls, and voice commands, have been extensively studied. However, they often overlook more intuitive and natural interaction methods that can further optimize user experience. Our proposed scheme introduces a dual-component framework encompassing gesture detection and command execution. By enabling users to control IVI functions such as play, pause, and volume adjustment through distinct hand gestures, this system enhances both user engagement and convenience. The integration of hand gesture recognition not only enriches the driving experience but also aligns with the broader goal of advancing human-computer interaction within vehicular environments. The results indicate that the proposed method significantly improves accuracy and user satisfaction compared to traditional interaction mechanisms. However, the project also encounters challenges, including the need for high-performance computing resources and robust internet connectivity for seamless data transmission. Additionally, the system's implementation in real-time scenarios necessitates sophisticated scripting and user-centric design to ensure accessibility and ease of use. In conclusion, this research represents a substantial advancement in IVI system interaction, offering a promising alternative to conventional methods. Future research should explore further optimizations and potential applications of gesture recognition technology to enhance interactive experiences across various platforms. The findings underscore the potential for gesture-based systems to transform user interfaces, contributing to both technological innovation and improved user satisfaction.

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BIOGRAPHIES OF AUTHORS

Wan Mohd Yaakob Wan Bejuri received his Ph.D., master and bachelor degree in computer science from Universiti Teknologi Malaysia in 2019, 2012 and 2009. Previously, he was received diploma in electronic engineering in 2005 from Politeknik Kuching Sarawak. He is currently a senior lecturer at Universiti Teknikal Malaysia Melaka. He can be contacted at email: yaakob@utem.edu.my.

Siti Azirah Asmai received his Ph.D. from Universiti Teknikal Malaysia Melaka. While master degree from United Kingdom, and bachelor degree from Universiti Teknologi Malaysia. She is currently a senior lecturer at Universiti Teknikal Malaysia. She can be contacted at email: azirah@utem.edu.my.

Raja Rina Raja Ikram received his Ph.D. and master degree from Universiti Teknikal Malaysia Melaka. While bachelor degree from University of Melbourne, Australia. She is currently a senior lecturer at Universiti Teknikal Malaysia. She can be contacted at email: raja.rina@utem.edu.my.

Nur Raidah Rahim received his Ph.D., master degree with bachelor degree from Universiti Teknologi Mara (UiTM). She is currently a senior lecturer at Universiti Teknikal Malaysia. She can be contacted at email: raidah@utem.edu.my.

Najwan Khambari received his Ph.D. from University of Plymouth, United Kingdom. While master and bachelor degree from Universiti Teknikal Malaysia Melaka. He is currently a senior lecturer at Universiti Teknikal Malaysia. He can be contacted at email: najwan@utem.edu.my.

Mohd Sanusi Azmi received his Ph.D., master degree and bachelor degree from Universiti Kebangsaan Malaysia. He is currently an associate professor and also current dean at Faculty of ICT, Universiti Teknikal Malaysia Melaka. He can be contacted at email: sanusi@utem.edu.my.

Yus Sholva is a program leader of informatic engineering at Fakultas Teknik, UNTAN. Currently, he is an associate professor at Universiti Tanjungpura, Indonesia. He can be contacted at email: sholvariza@untan.ac.id.