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Enhancing Driver Comfort and Control: A Proposal for Customizable Gas and Brake Pedal Sensitivity

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Abstract: Despite spectacular advancements in automotive industry, a significant gap exists within the domain of driver-vehicle interaction like the fixed response force of the accelerator and brake pedals. Nowadays, although there are studies on safety especially for pedals, the issue of customizing the pedal hardness has not become widespread. In this study, a method for customizing the accelerator and brake pedals is suggested. The proposed system improves driving comfort and experience by allowing drivers to customize their preferred pedal level. Utilizing an accessible tuner for stepwise adjustments, drivers can fine-tune the pedal response force until it matches their comfort and driving style. Moreover, our system includes numbered preset buttons, which enable drivers to save their preferred force profiles. This feature not only accommodates the unique preferences of individual drivers but also eases transitions between different drivers sharing the same vehicle. By just a push of a button, drivers can recall their saved profiles, ensuring consistent comfort and control across different driving sessions. By incorporating this system to the car, we aim to revolutionize driver-vehicle interactions, moving away from the traditional standardized approach towards a personalized driving experience. This novel solution holds promise in expanding driving comfort, improving vehicle control, and potentially enhancing driving safety. Furthermore, it creates new avenues for research into the effects of tailored pedal forces on driving efficiency and fatigue, thus shaping the future trajectory of automotive design.

Keywords: Gas and brake pedal, Sensitivity, Driving efficiency, Driver comfort

Introduction

Personalization is essential for addressing user needs in today's rapidly expanding and changing technological world. By offering them specialized solutions, personalization has the ability to improve people's interactions with technology. By supplying automobiles that are in line with drivers' choices and demands, personalization in the automotive industry offers a distinctive driving experience. The trend of personalization aims to cater to individual demands in the automotive sector, ranging from the interior and exterior design of vehicles to their technological features. This trend was the biggest motivation in creating this study. It is known that there have been ongoing studies for years regarding personalization in vehicles and specialized systems around the driver. In a past study, issues such as improving user experiences while driving and driver-based automotive user interface design were discussed. At this point, the point that issues such as entertainment, comfort and driving assistants are specifically designed for the driver is mentioned (Kern & Schmidt, 2009). In another paper, the active fatigue state of the driver was observed, and the adaptive cruise control system values were dynamically changed accordingly, thus this appears as a customized study focused on the driver (Chen et al., 2014). Automatic adjustment of the mirrors according to the driver's perspective, placing the driving parts in optimum positions according to the driver's physical characteristics, and voice commands or other functions can be performed in the vehicle with the driver's voice identity. Adjusting the seat and mirror angles are just two simple examples of car customization features.

The ability to customize the stiffness of gas and brake pedals in vehicles holds significant importance as it allows drivers to fine-tune their driving experience based on their personal preferences and comfort levels. Moreover, it is crucial in ensuring optimal control and responsiveness, enabling drivers to tailor their driving dynamics to suit their individual needs and driving styles. Another important motivation and starting point while doing this study was the studies in the literature on pedal feel and stiffness. The idea of recording pedals specifically for the driver and then applying them to the personalization and profiling trend in the automotive industry has been the leading aim of this study. If we look at past studies on pedal sensitivity, a dynamic model was developed regarding the feel of the brake pedal and as a result of the simulations, it was stated that the brake system in that study was usable (Meng et al., 2015). In our study, it was thought that each driver could have a gas or brake pedal sensitivity that they felt comfortable with, and improvements were made accordingly. In another study, it was aimed to provide stable brake feeling and an optimization model was developed. This system, which is suitable for cable brake systems, provides the opportunity to adjust the brake pedal feeling differently (Aleksendric et al., 2015). As a result of the pedal hardness being adjustable, the driving comfort and performance of at least 2 drivers driving the same vehicle will be improved. In addition, a single driver can set different modes according to himself and save them for different paths.

It has been observed that some automobiles on the market have an adjustment for the firmness or height of the brake and gas pedals, according to various research that has been done on the subject (Lexus Parts, n.d.). Finding the appropriate setting for each driver will be a hassle, as many of the previous studies offered a mechanical solution and lacked user-specific customization. In our study, since the pedal hardness of the profile is kept digitally in a system, it is possible to switch between profiles with a single key. The pedal stiffness study is of a nature that improves the automotive sector, which is affected by the transition from centralization to personalization in technology. It aims to increase driving comfort and efficiency.

Materials

Potentiometer

A potentiometer is a variable resistor that can be used to control the flow of electric current. It consists of a resistive element, such as a metal wire or a carbon strip, with a movable contact called a wiper. The wiper is connected to a terminal, and the two ends of the resistive element are connected to the other two terminals. (Potentiometer, 2023).

The working principle of a potentiometer is based on the potential drop across any section of a wire is directly proportional to the length of the wire, provided the wire is of a uniform cross-sectional area and a uniform current flow through the wire.

When a constant current flows through a potentiometer, the potential difference between the wiper and either end of the resistive element is proportional to the distance between the wiper and that end. This means that the potentiometer can be used as a voltage divider (Analog Devices, n.d.). Potentiometers are used in a wide variety of applications such as volume controlling device, brightness controlling device. In this study, it is also used as a controller for the sensitivity of the gas and brake pedals.

Analog Digital Converter (ADC)

An Analog-to-Digital Converter (ADC) is an electronic circuit that converts analog signals into digital data. This circuit enables varying continuous voltage or current signals to transform from the analog world to digital data (Storr, 2023). The converted data is applicable to be processed by microcontrollers or other digital systems.

The potentiometer used to determine the hardness of the accelerator pedal produces an analog signal. The ADC measures the analog signal from the potentiometer at a specific sampling rate. The sampling process ensures that the analog signal is measured at regular intervals. These intervals represent the continuous variation of the signal, and the value of the analog signal is obtained at a specific time (Agarwal, 2021).

Microcontroller Unit (MCU)

Microcontrollers (MCUs) or other control units are employed. MCUs are integrated circuits utilized for processing, controlling, and managing analog and digital signals. The MCU receives the digital signal from the potentiometer and processes it according to a specific algorithm or programming logic (Brain, 2000). This programming is employed to evaluate data related to the position of the accelerator pedal, control power transmission, or perform other relevant functions (tutorialspoint, n.d.).

Gas and brake pedal sensitivity system was implemented using the NXP S32K148 microcontroller platform. The NXP S32K148 is a 32-bit microcontroller centered around the ARM Cortex-M4 core, specifically designed for applications in the automotive industry. This microcontroller meets the high-quality standards required by the automotive sector, ensuring reliable performance even in the challenging automotive electronics environment. It adheres to the AEC-Q100 standards, and it is fully compliant with the safety requirements outlined in ISO 26262. These qualities make it a suitable choice for integration into safety-critical systems (NXP, n.d.).

Non-Volatile Memory (NVM)

Non-volatile memory (NVM) is a type of computer memory that can keep data even when the power is turned off. This is unlike volatile memory, such as DRAM, which loses its data when the power is turned off. NVM is typically used for long-term storage, such as in hard drives, solid-state drives (SSDs), and memory cards. It is also used in some embedded systems, such as those found in cars and other devices (“Non-volatile memory”, 2023). In this study, non-volatile memory was used to permanently retain pedal sensitivity data that the driver has set and saved. The use of NVM has become inevitable since data needs to be stored in situations such as when the vehicle is not in use or there is a power cut.

Method

In this study, an MCU-based system design is presented to increase the comfort of the drivers and customize the driving experience by adjusting the sensitivity of the accelerator/brake pedal. The system has the ability to adjust the response characteristics of the accelerator and brake pedals according to the preferences of the drivers. The block diagram describing the system in a simple way is shown in Figure 1.

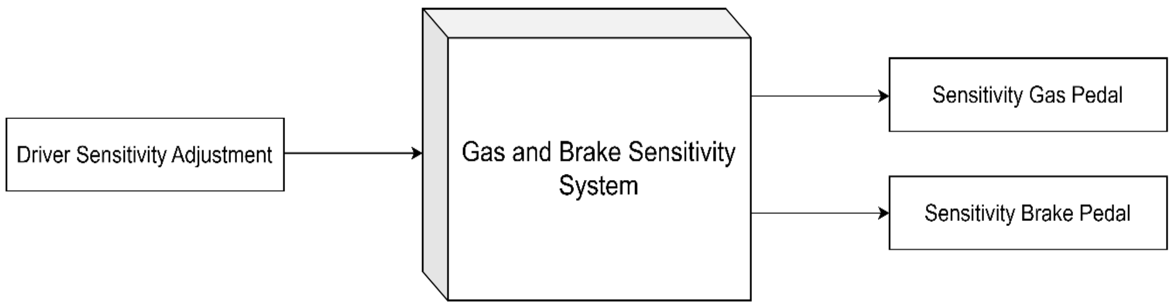

Figure 1. Gas and brake pedal sensitivity system high level block diagram

The system employs potentiometers to ascertain the sensitivity levels of the accelerator and brake pedals. Potentiometers generate a voltage output that varies in proportion to the force applied by the driver on the pedals. This voltage signal is then read by an ADC unit connected to the NXP S32K148 MCU. The MCU is responsible for converting the analog voltage signal acquired via the ADC into digital data for further processing. The driver's determined sensitivity level can be stored within the system as a personalized profile, and this registration process is typically facilitated through designated buttons.

This procedure allows the driver to fine-tune their pedal sensitivity to craft a bespoke driving experience. For instance, if a driver desires a more delicate throttle response, the system can be configured to deliver increased acceleration when the pedal is lightly depressed. Similarly, analogous sensitivity adjustments can be made for the brake pedal.

The user interface of the system presents a platform for the driver to adjust these preferences, enabling them to save these settings within a profile. These profile settings can then be stored for later retrieval, offering a customized driving experience tailored to individual preferences. This system empowers drivers to personalize their driving experience, enhancing both comfort and control, ultimately resulting in a more enjoyable time behind the wheel. The user interface of the system is shown in Figure 2.

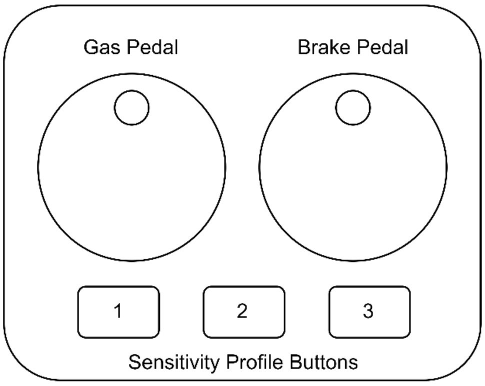

Figure 2. Gas and pedal sensitivity system user interface prototype

The driver initiates the system's recording mode by pressing and holding down the designated profile button. The duration of the button press is scrutinized to determine if the driver has commenced profile recording. An interrupt handler is employed to identify when the button has been held down for an extended period. It is considered that the driver has executed a long press when the predefined LONG_PRESS event threshold is surpassed. Upon detecting this long button press, the system transitions into recording mode. Figure 3 illustrates the flowchart showing the capture processes of button events.

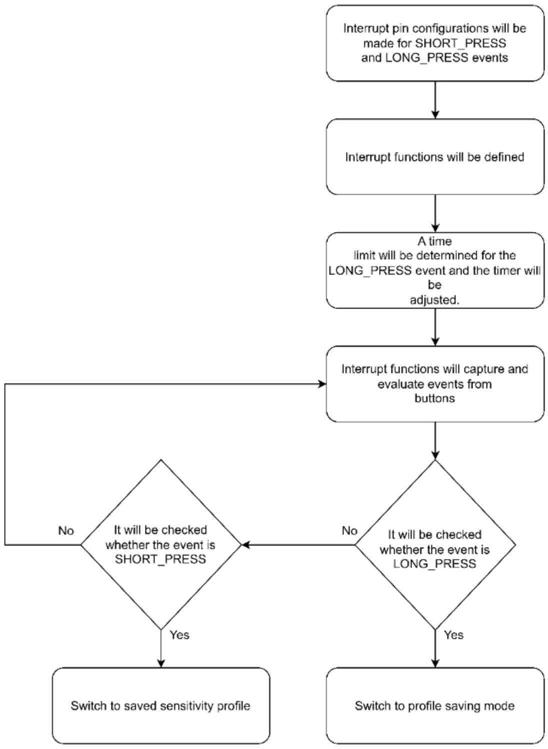

Figure 3. Button press event flow chart

To communicate this transition, the user LED associated with the selected profile blinks, signaling to the driver that the system has entered recording mode. The flashing user LED serves as a visual indicator to convey the system's recording status to the driver. Once the system has entered recording mode, the driver gains the ability to fine-tune the sensitivity of the accelerator and brake pedals to suit their personal comfort preferences. These sensitivity adjustments are executed by manipulating potentiometers. The data output from these potentiometers is captured and subsequently processed through the ADC.

In essence, this sequence of events allows the driver to record their preferred pedal sensitivity settings within the chosen profile while providing a clear visual indication through the user LED that the system is actively recording. This ensures a seamless and user-friendly means of customizing the driving experience.

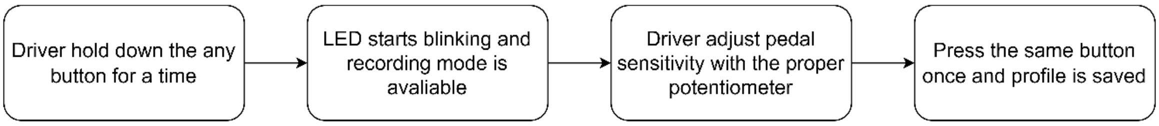

Figure 4. Setting and saving sensitivity for a profile flowchart

In this research project, a system is employed to finely adjust the sensitivity of both the accelerator and brake pedals. To ensure that the digitally configured pedal sensitivity settings are retained in memory, it is imperative to convert the values set with these potentiometers into a digital format on the platform. This critical task is accomplished through the utilization of the ADC integrated within the MCU.

The first pivotal step in this process is the meticulous configuration of the ADC settings. The ADC module embedded within the MCU necessitates a thorough configuration, encompassing the selection of the ADC's operating mode, resolution, reference voltage, and various other parameters. The configuration process is executed with careful reference to the comprehensive documentation provided by the MCU's manufacturer.

For the operating mode of the ADC, the 'continuous conversion mode' is deliberately chosen. In this mode, the ADC incessantly samples and transforms an analog input signal into a precise digital representation. This continuous operation ensures that when the driver initiates the pedal sensitivity adjustment, the ADC diligently reads and translates the analog values throughout the duration of this process.

The configuration of the ADC settings is a critical precursor to the successful digitization of pedal sensitivity settings, guaranteeing a highly responsive and accurate means of translating the driver's preferences into a digital format for further processing and system memory retention. Another crucial aspect of ADC configuration pertains to the setting of ADC resolution. ADC resolution defines the number of digital bits allocated to represent the amplitude of an analog input signal. It essentially dictates the precision or granularity of the digital representation. In this specific research, the ADC embedded within the MCU is configured with a resolution of 4096. It's worth noting that the MCU's documentation specifies a 12-bit ADC with a precision ranging from 2 to 12 bits. By selecting a 12-bit resolution, the system ensures a high degree of precision in translating the analog input signals into their digital counterparts.

Moving on, the definition of the reference voltage value is the next critical configuration step. Given that the MCU's documentation designates the ADC's reference voltage as 3 Volts, the reference voltage is meticulously set to precisely 3 Volts. Consequently, this establishes the full-scale range of the ADC, ensuring that it effectively covers the entire spectrum of voltages within its operational capacity.

The second facet of ADC configuration involves the setup of General-Purpose Input/Output (GPIO) pins that are designated for ADC operations. The selection and configuration of these GPIO pins are fundamental to the successful integration of the ADC into the system. This configuration process is executed through the utilization of specific software libraries designed for this purpose. By carefully designating and configuring the relevant GPIO pins, the system ensures seamless communication between the analog input sources, such as the potentiometers responsible for pedal sensitivity adjustments, and the ADC module within the MCU. This critical step is pivotal in enabling the ADC to accurately sample and convert the analog input signals into digital data, facilitating the precise adjustment of pedal sensitivity settings as per the driver's preferences.

The final and crucial step entails initiating a continuous loop responsible for reading the analog signals that have been fine-tuned using the potentiometers connected to the ADC. The system must maintain an uninterrupted transition from analog to digital conversion as long as the driver is adjusting the pedal sensitivity settings. To achieve this, the previously configured ADC settings are integrated into the software, and the loop is set into motion.

Even at this juncture, the software permits the definition of the delay duration between two successive analog data readings. This delay, often referred to as the sampling rate, plays a pivotal role in the precision of the digital conversion process, as it determines how frequently the ADC samples the analog input.

The obtained unit voltage value is derived through a systematic process. Initially, the read analog value is divided by the ADC's resolution. This division yields a normalized value that reflects the unit voltage change per digital bit. Subsequently, the final calibrated digital value is calculated by multiplying this normalized value by the reference voltage value, which has previously been established as 3 Volts.

In essence, this final step in the process ensures that the system consistently and accurately translates the analog adjustments made by the driver into precise digital representations. This continuous loop operation guarantees that the pedal sensitivity settings can be tailored to the driver's preferences with a high degree of accuracy and responsiveness, facilitating a finely tuned driving experience. The algorithm created for reading the data from the potentiometer is shown in Figure 5.

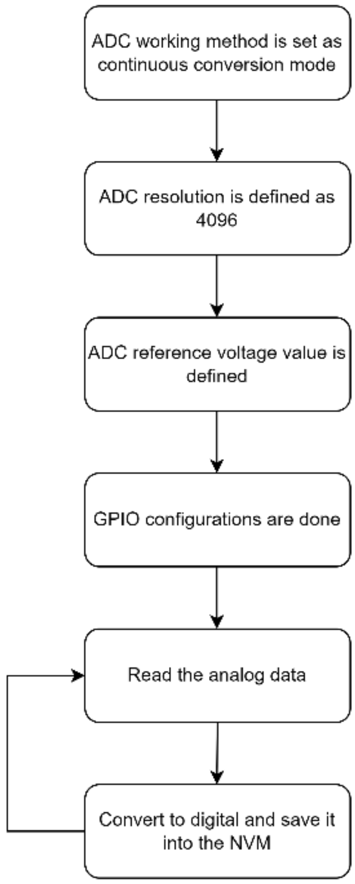

Figure 5. Flowchart for reading potentiometer data

Once the driver has fine-tuned the sensitivity settings to their preference, they finalize the profile recording process by activating the save function through the profile button. In this scenario, the system detects a SHORT_PRESS event triggered by the button press. With the SHORT_PRESS event, the system proceeds to store the gas and brake pedal sensitivity data, meticulously customized by the driver, into the NVM. This storage ensures that the driver's preferred settings are retained and can be recalled in future usage.

To provide feedback to the driver and confirm the successful completion of the recording process, the user LED is employed. The user LED, which typically blinks during the recording process, transitions into a continuous and steady illumination state as the SHORT_PRESS event is detected, signaling the completion of the recording procedure. This serves as a visual indicator to communicate to the driver that their personalized pedal sensitivity settings have been securely saved and that the recording operation has been successfully executed.

The data saving operation takes place on NVM while creating the profiles in the study. This internal memory of the MCU selected within the scope of the project was managed by the flash driver functions. In addition to simple flash operations such as reading, writing and deleting, operations such as partitioning and allocating depending on the number of drives in the initialization section also had to be handled. As shown in Figure 6, the operations performed on NVM in different use cases are presented.

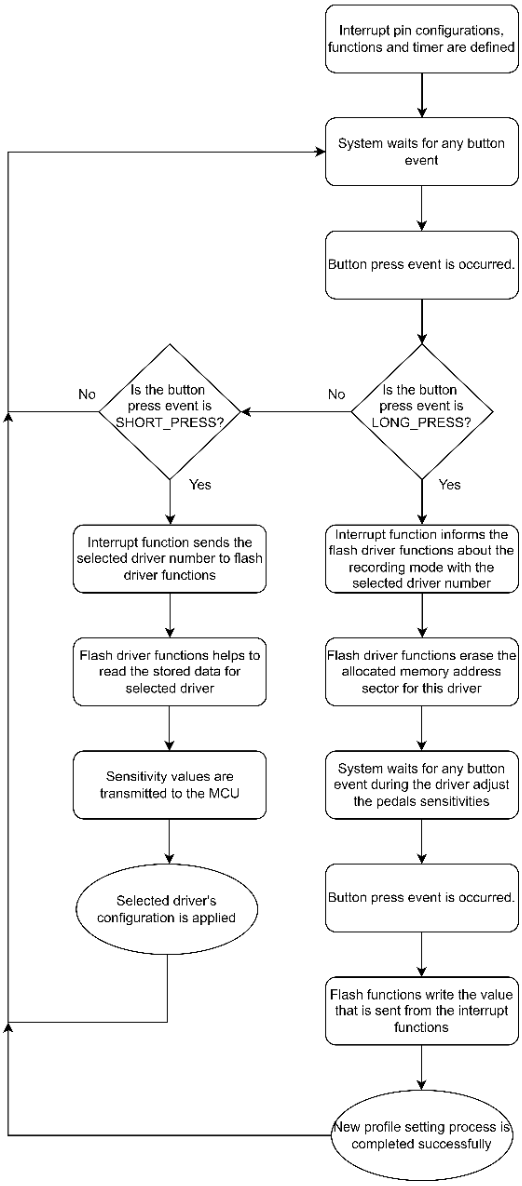

Figure 6. Flowchart for NVM management for different cases

This endeavor to tailor the sensitivity of both the gas and brake pedals also encompasses a mechanical component. This mechanical system is intricately controlled by the ADC values derived from potentiometers. The heart of this mechanical arrangement lies in the presence of springs positioned behind both the gas and brake pedals. These springs are designed to exhibit bidirectional movement, achieved through the adjustment of a screw mechanism that interfaces with a potentiometer, offering a remarkable 4096 distinct digital positions. In other words, this system allows for the controlled extension and compression of these springs within a defined range.

At the minimum potentiometer value, the spring is stretched to a point where its mechanical properties remain unimpaired, rendering the pedal at its softest configuration. Conversely, at the highest potentiometer value, the spring is compressed to its maximum extent, resulting in the stiffest pedal configuration possible. This design affords the driver the flexibility to finely calibrate the pressure applied to the pedal, enabling them to choose between a softer or firmer pedal feel. By adjusting the potentiometer, the driver can pinpoint the precise level of sensitivity that suits their preferences and record it within their personal profile.

Figure 7 illustrates the overarching structure of the system, featuring a preliminary design that incorporates the pedal-side components, providing a visual representation of this mechanical mechanism. This fusion of mechanical and electronic elements ensures a highly customizable and responsive driving experience, catering to the distinct preferences of each driver.

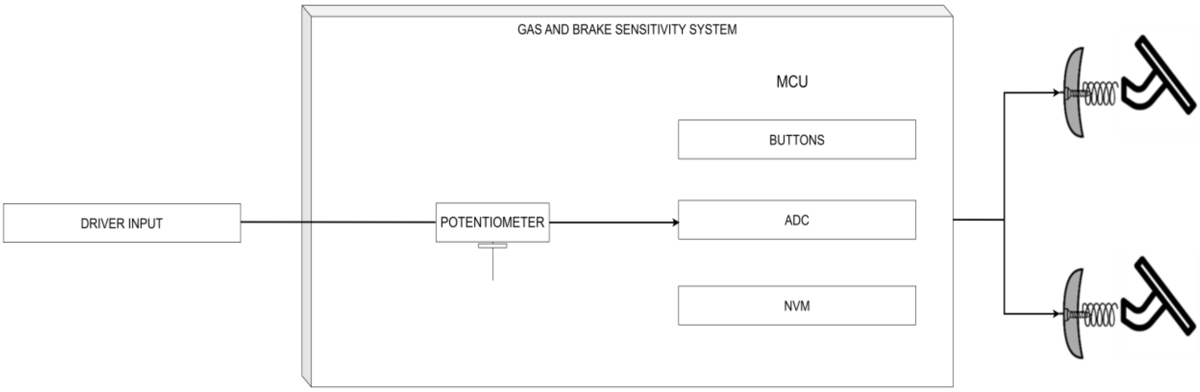

Figure 7. General design of the system

The innovative system design presented herein empowers drivers with a unique and sophisticated capability—the ability to finely calibrate the sensitivity of both the gas and brake pedals. This advanced feature not only prioritizes driver comfort but also offers a wealth of advantages, including the personalization of the driving experience and an enhancement in overall operational efficiency.

Moreover, this customization extends to an enhancement in driving efficiency. With the ability to adjust pedal sensitivity, drivers can optimize their driving style for various road conditions and driving scenarios. For instance, in stop-and-go traffic, a softer pedal response may reduce fatigue, while in sportier driving situations, a firmer pedal feel could enhance control and responsiveness. The system's adaptability enables a dynamic response to changing driving conditions, thus increasing driving efficiency and safety.

Results and Discussion

Customizable vehicle systems offer significant advantages to the driver during the act of driving. These systems allow drivers to tailor their vehicles to their preferences. Such systems not only enhance the driver's comfort but also increase driving safety. In this context, studies have been conducted to investigate the impact of adjustable pedal systems, which are part of customizable vehicle systems, on driver comfort. In a study, twenty volunteers were tested in small and large vehicles equipped with adjustable pedals at three pedal positions. Observations revealed that the use of adjustable pedals in both vehicles was influenced by factors such as visibility, knee-steering wheel contact, and arm posture. It was observed that the amount of heel lifting decreased when the short-statured group transitioned from the normal to comfortable/maximum tolerable positions. The results underscore the utility of adjustable pedals, particularly for short-statured drivers in large vehicles (Parenteau et al., 2000).

Our system, allowing drivers to adjust the stiffness of the gas and brake pedals to enhance their driving comfort and efficiency, stands out with its ease of use and straightforward integration. The methodologies employed in the development of this system, are meticulously detailed in the Method section. The tools, devices, and technologies harnessed for the implementation of this study are comprehensively outlined in the Materials section. This research project is intrinsically geared towards enhancing both driver comfort and vehicle performance by the creation of distinct driver profiles.

The system, designed to cater to the preferences of three different drivers, utilizes a combination of buttons, each assigned unique functions, and rotary knobs that facilitate the adjustment of pedal stiffness. This integration allows for the digital storage of customized profiles for each driver, enabling swift activation of their respective settings prior to commencing a drive.

A significant achievement of this study is the mitigation of the issue of pedal stiffness disparities encountered across different vehicles. Additionally, the driving experience is markedly enhanced by the ability to fine-tune pedal sensitivity, thus ensuring each driver's personal comfort is accommodated, even within the same vehicle. Beyond these accomplishments, this research project introduces a pioneering perspective on the evolution from centralized to decentralized structures within the technology sector.

In addition to the visionary outlook this study offers in terms of pedal stiffness personalization, it carries the potential to contribute to emerging technical concepts that are increasingly being integrated into a myriad of projects. Notably, the study lends itself to the realm of machine learning. Here, the system, after a driver configures their pedal settings, can continuously monitor and record data pertaining to fuel consumption and vehicle performance in relation to the force exerted on the pedals. Utilizing machine learning algorithms, the system can then make recommendations for optimizing settings, thereby not only enhancing vehicle performance but also elevating the overall driving experience.

Additionally, in a previous study, the effect of the adjustable pedal structure on causing an accident based on the in-vehicle control mechanisms and the changes that may occur on the driver's side were examined. According to this study, it was concluded that this pedal adjustment was not a serious threat, since the in-vehicle control mechanisms caused very few accidents during the year in North Carolina. Since pedal adjustment will not occur during the journey, this work cannot be a factor in the accident. Moreover, as a result of this study, it was concluded that pedal adjustment provides a slight improvement in issues such as speed, control and lane keeping. Therefore, these results will be similar for driver-specific pedal sensitivity adjustments (Young et al., 2001).

In summary, this research project represents a fusion of innovative methodologies and advanced technologies, culminating in a system that provides unprecedented personalization of pedal stiffness. The implications extend beyond enhanced driver comfort, encompassing the realms of vehicle performance and the broader adoption of decentralized technological frameworks, offering a glimpse into the future of personalized and intelligent automotive systems.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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