

A Tailgate(Trunk) Control System Based on Acoustic Patterns

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ABSTRACT

When customers use a tailgate (or trunk), some systems such as power tailgate and smart tailgate have been introduced and implemented for improving convenience. However, they still have some problems in some use cases. Some people have to search for the outside button to open the tailgate, or they should take out the key and push a button. In some cases, they should move their leg or wait a few seconds which makes some people feel that it is a long time. In addition, they have to push the small button which is located on the inner trim in order to close the tailgate. This paper proposes a new tailgate control technology and systems based on acoustic patterns in order to solve some inconvenience. An acoustic user interaction (AUI) is a technology which responds to human's rubbing and tapping on a specific part analyzing the acoustic patterns. The AUI has been recently spotlighted in the automotive industry as well as home appliances, mobile devices, musical instruments, etc. The AUI is a technology that can extend to rich-touch beyond multi-touch. The AUI can be easily applied and adapted even to the systems which need a large touch recognition area or have complex shape and surface. This paper addresses how to recognize the users' intention and how to control the tailgate using acoustic sensors and patterns. If someone who has the smart key wants to open the tailgate, he or she only needs to knock on the outer panel of the tailgate twice. When they want to close the tailgate, just touching anywhere of the inner trim of the tailgate will do. Various digital filters and algorithms are used for acoustic signal processing, and the effectiveness of the proposed methods is shown by a real tailgate system with a micro control unit. Finally, we suggest other applications of vehicles which use AUI technology.

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INTRODUCTION

Vehicle users want a car to be controlled as much as they want and at the right moment when they want to open or close the trunk/tailgate of the car. And there is a door lock system in the trunk/tailgate for anti-theft and safety. So we have to manipulate a separate button in a smart key or in a trunk/tailgate to release the lock. Many automotive companies have tried a variety of technologies in order to improve convenient operation while maintaining the stability of the car trunk/tailgate. To accomplish that, a power trunk/tailgate system actuated by motors has been applied to automatically opening and closing by some companies. In addition, the hands-free liftgate system which enables the tailgate to be opened by simply kicking your foot underneath the rear bumper has been introduced by a car maker [1]. The other car maker has proposed the smart trunk/tailgate system which allows the trunk/tailgate to be automatically operated when users are standing with the proximity smart key for more than three seconds within a meter of the rear of the vehicle [2].

The convenience for opening or closing the tailgate has been much improved since the power tailgate system was introduced. But it is still needed to use a button or a switch on the outer panel or inner trim for conveying the exact user's intent. Users would experience unpleasant while searching the handle switch on the dirty tailgate to open. Sometimes they encounter the situation to urgently find the inner button to stop the tailgate when the tailgate closes

unconsciously. Someone should awkwardly move their legs at the rear of the car, or some should stand for over three seconds which might be a long time to somebody. In order to solve these problems, a new tailgate system based on acoustic patterns is suggested in this paper while assisting the conventional tailgate function.

Various methods that can recognize human touch and control vehicle systems using an acoustic wave have been recently introduced. The acoustic user interface (AUI) can provide users with the experience of the rich touch beyond the multi-touch. The AUI can be applied to IT devices to perform special functions, and AUI also can be used in analyzing the human body vibration to control a wearable device. In addition, The AUI can be applied to various media comparing to other touch technologies. Therefore, the AUI is considered as a novel touch technology which can be also used on the wide and complex surface of a system [5, 6, 7, 8, 9, 10, 11, 12, 13].

The system presented in this paper is about a technology that uses acoustic waves and patterns to recognize the users' intention and to control the tailgate (trunk) of cars. The system can control the tailgate depending on the input patterns recognizing the vibration features from the panel or the trim. When a user wants to open the locked tailgate, the tailgate can be immediately opened if the user taps twice on the outer panel of the tailgate. On the other hand, if the user wants to close the tailgate, the tailgate will be immediately closed when the

user lightly taps once on the inner trim of the tailgate. If you want to have the moving tailgate stop, it is only needed to tap once on the inner trim.

The purpose of the AUI tailgate system development is addressed in the first section. The overall structure of the proposed system and method is described the second section. In following sections, the basic principle of signal conversion, pattern recognition, and implementation process are described. Finally, the feasibility of the proposed system and algorithm is shown through experiments using an actual tailgate system.

DEVELOPMENT OBJECTIVES

The development targets of the acoustic user interface based the tailgate system are as follows:

- Improving customers' convenience by intuitive behavior recognition
- Ensuring price competitiveness with inexpensive parts
- Ensuring system stability while preserving the functions of the pre-installed power tailgate.
- Enhancing the differentiated marketability with exclusive technology
- Modularizing system for rapid application in various other automotive systems

System Configuration and Operation

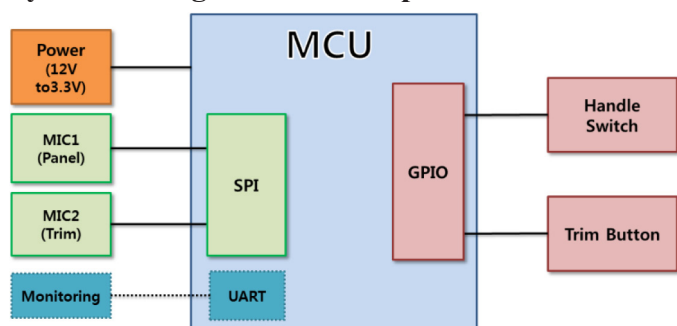


Figure 1. The overall hardware structure of the AUI tailgate controller

Figure 1 shows the overall structure of the proposed system. Cortex-M4 is used for the core of the micro control unit (MCU), and operation clock speed is 100MHz. The system is currently using the main power of a car, so it is needed to monitor the voltage of the main power. The MCU can be entered to the power down mode when the system detects the low voltage level of the main power, under 10V, by a DC-DC converter. There is approximately 30mA current consumption in the normal condition, but about 6uA current is consumed in the power down mode.

A MEMS MIC (Micro-Electro-Mechanical Systems Microphone) is used for an acoustic sensor, and two MICs are used; one is for the outer panel and another is for the inner trim. The received acoustic signals are converted and outputted to PDM (Pulse Density Modulation) signals via the MIC. The MCU receives the PDM signals through two SPI ports of the MCU and converts them into

PCM (Pulse Code Modulation) signal by transfer functions operated in the MCU. The process of transforming the PDM to PCM will be described in the following section.

A pattern recognition logic running in the MCU can distinguish whether the input is intentionally made by human or other causes. The pattern recognition logic can figure out specific patterns and features in the acoustic signals. When it is determined that a person intentionally made some acoustic signal or vibration, the MCU will generate the handle switch signal of the outer panel or the button signal of the inner trim corresponding to the recognized input pattern. One UART (Universal Asynchronous Receiver/Transmitter) port is used to monitor the state of the MCU or the signal from the MIC.

Figure 2 shows the current developed MCU and MIC modules. These modules are installed between the outer panel and the inner trim. The MIC1 is attached on the inside surface of the outer panel, and MIC2 is attached on the inside surface of the inner trim.

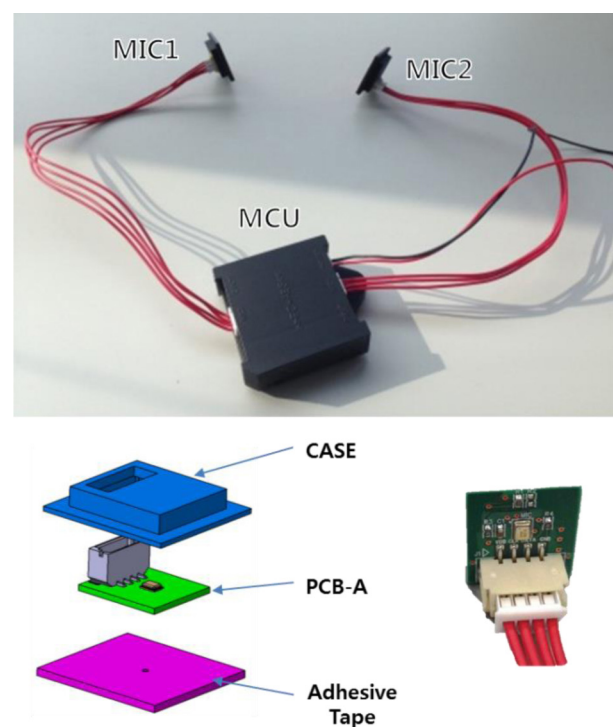


Figure 2. The developed MCU and MIC modules

Some examples of gestures for opening and closing the tailgate is shown in Figure 3. The tailgate will be opened when the user knocks on the outer panel of the tailgate twice. In the state of the tailgate opened, the tailgate will be closed when the user hits once on the inner trim of the tailgate. While having the tailgate moved, the user can make the tailgate stop if he or she hits once again the inner trim. If the user knocks on repeatedly the trim from time to time, then the tailgate sequentially repeats closing and opening.

The AUI tailgate system preserves the functions of the previously installed power tailgate. So it is necessary for users to keep their smart (or proximity) key near the tailgate to operate the power or AUI tailgate. It prevents anybody opens the tailgate without key access.



Figure 3. Knocking gestures to open or close the tailgate

CONVERSION OF PCM FROM PDM SIGNAL

The MEMS MIC was chosen as a digital MIC instead of a conventional analog MIC for the acoustic sensor since the digital MIC is robust to the electromagnetic noise. When a user knocks on the panel or the trim, it causes a vibration of the material, and the vibrated waves are propagated through the media, the panel or the trim. The acoustic wave can be propagated faster and less attenuated in a rigid material than in the air. The propagated waves are converted into electrical signals through the membrane — a sort of diaphragm — within the MEMS MIC. Then the electric acoustic signals are converted again into PDM signals through the ASIC within the MEMS MIC. The PDM signal can be transferred in 1-bit digital signals, so the transmission line requires only the signal line and the clock line needed for synchronization. Of course, the two power lines are required for operation. The acoustic signals are converted to the PDM signal by Equation (1). The result of $y[n]$ will be 1 if the current $x[n]$ is more than the previous difference $e[n-1]$. Otherwise, it will be 0 [3,4].

$$y[n] = \begin{cases} 1, & x[n] \geq e[n-1] \\ 0, & x[n] < e[n-1] \end{cases}$$

$$e[n] = y[n] - x[n] + e[n-1] \quad (1)$$

Where,

$x[n]$ = current original signal

$y[n]$ = output of the delta-sigma modulator

$e[n]$ = quantization error of the delta-sigma modulator

The PDM signal is transmitted by one of the SPI port of the MCU as we can see in Figure 1. The overall hardware structure of the AUI tailgate controller. The sampling rate of the acoustic signal is 16KHz, the clock frequency for the MIC is 1.024MHz as the decimation factor is 64. The one-bit PDM signals synchronized to 1.024MHz clock is transferred to the MCU and stored into a 32-bit buffer in order. When the number of the stored data is over than 32, the average bit value is calculated. The average value is recorded in sequence into a particular memory. Then after storing data as many as 20ms, the bandwidth of the signal becomes to half of the stored signals by an IIR BPF(Infinite Impulse Response Band Pass Filter). After that, the final data can be obtained through a FIR BPF(Finite Impulse Response Band Pass Filter) and a decimation filter. The final

data is described in a 32-bit float of PCM, the amplitude of the signal can be adjusted through the parameters of the filters. The overall process from PDM to PCM is shown in Figure 4.

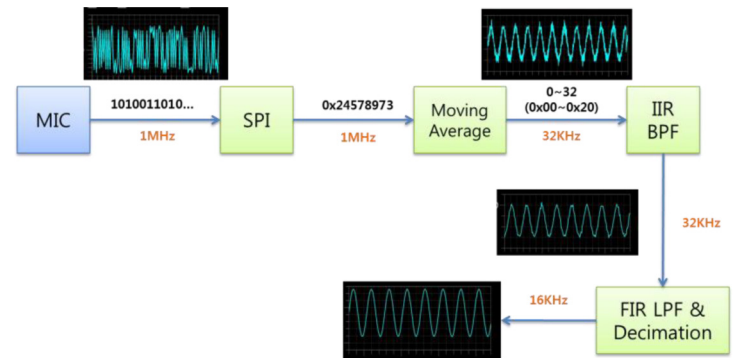


Figure 4. Conversion process from PDM to PCM [7]

THE PROCESS AND METHOD OF ACOUSTIC PATTERN RECOGNITION

Overall Structure of Algorithm

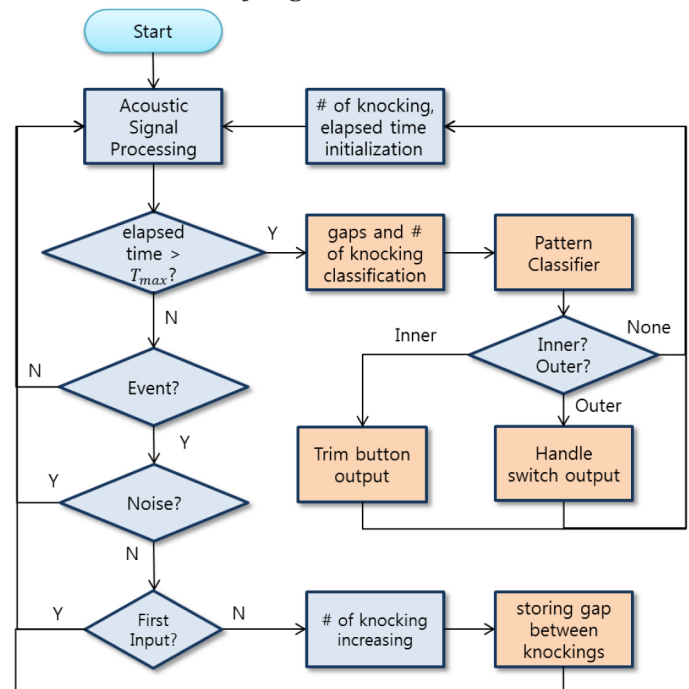


Figure 5. Acoustic pattern recognition process

Figure 5 displays the overall process that determines whether the input signal is made by users or not using the acoustic signals of converted PCM. After the MCU start operating, the acoustic signals are input and processed in 16KHz sampling rate in real time. Sectional powers are measured in every 20ms, and some events can be detected when the sectional power value is above the predetermined value. The period of 20ms is known as an appropriate time to monitor the variation of acoustic energy according to the previous researches. If the fastest rhythm a human can make is considered about 10Hz (100ms in time), the unit of 20ms can be effective to detect impulse inputs [14-15].