

An Innovative Capacitive Knob Design with Press-and-Rotate Function for Automotive In-Cell Touch LCD

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Abstract

The knob provides an excellent user experience for automotive displays by offering tactile feedback through physical controls. However, the prior knob had limitations, particularly its inability to support press-and-rotate function. In response, an innovative knob design has been proposed and proved effective through simulations, enabling press-and-rotate function and versatile positioning for automotive in-cell touch LCDs.

Author Keywords

Knob; In-cell touch LCD; Touch sensor; Automotive; TDDI.

1. Introduction

The touch function provides an intuitive user experience that originated from consumer electronics and has become the most familiar human-machine interface for displays. Automotive displays have also followed this trend. Many traditional mechanical knobs and buttons have been replaced by the center information display (CID). This trend has driven user interfaces to be simpler and more consistent, allowing users to control various functions via a single touch panel. Furthermore, in-cell touch LCD technology offers greater design freedom and a better cost structure, making it a leading solution for automotive display systems. In-cell touch LCDs use capacitive sensing technology. As shown in Equation (1) and Fig. 1, the in-cell touch sensors measure the capacitance difference between a human finger and the sensors, which is based on the parallel plate capacitor equation:

$$C_F = \epsilon \left(\frac{A}{d} \right) \quad (1)$$

where C_F is the capacitance between the finger and the touch sensor, ϵ is the absolute permittivity of the dielectric material, A is the overlapping area between the finger and the sensors, and d is the distance between the finger and the sensors.

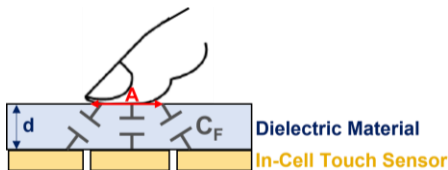


Figure 1. Capacitive sensing with the in-cell touch sensor

However, replacing physical controls with a touch panel has led to unintended actions while driving, which may negatively affect user experience due to increased accidental touches [1]. This indicates that tactile feedback remains important for drivers. It allows the drivers to control smoothly while keeping their eyes on the road, thereby ensuring driving safety. Therefore, the knob on display solution was proposed to combine the advantages of tactile feedback and the touch panel without requiring any modifications to the panel [2][3][4]. In this work, we introduce an innovative capacitive knob design with press-and-rotate function for the automotive in-cell touch LCD.

The knob is a cylindrical device with an internal mechanical structure and electrodes at the bottom. When it is integrated with an in-cell touch LCD, there is no need to create openings in the

panel or add additional wiring. It operates by simply attaching the bottom of the knob to the touch panel. When the knob is not in use, the bottom electrodes remain floating, and the in-cell touch sensors cannot detect any changes in capacitance. When the user rotates the knob, as shown in Fig. 2(a), their finger touches the conductive ring at the top, which connects to the bottom electrodes through the internal mechanism. This connection extends the electric potential of the finger to the bottom conductive electrodes, allowing the in-cell touch sensors to detect the change in capacitance C_K and determine which knob function is being used. Fig. 2(b) shows a top view of a knob application example, and Fig. 3 illustrates a demonstration of knob manipulation on an in-cell touch LCD.

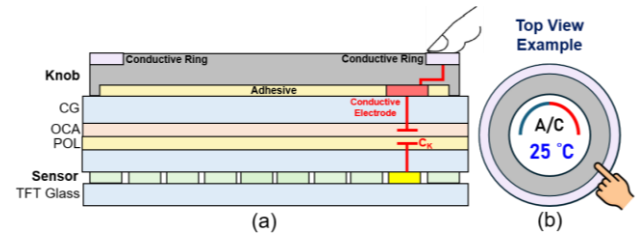


Figure 2. (a) The knob structure with the in-cell touch LCD (b) The top view of a knob application example



Figure 3. Knob manipulation demonstration on the in-cell touch LCD

2. The Knob Design

(a) The Prior Knob Design and its Limitations

As shown in Fig. 4(a), the prior knob features three conductive electrodes at its bottom, which are fixed onto the touch panel. These three conductive electrodes, named A Pad, B Pad, and C Pad, form capacitances with the touch sensors under them, which are denoted as C_{KA} , C_{KB} and C_{KC} respectively. When the user touches the knob, a conductive path is established from one of the conductive electrodes to the user's finger via the longer contact, rotary wheel, and conductive ring. As the user rotates the knob, the internal mechanism ensures that the three conductive electrodes sequentially connect to the user's finger, with only one electrode connected at any given rotation state. Thus, only one of C_{KA} , C_{KB} , or C_{KC} will have a non-zero capacitance signal, while the other two will be zero. Based on the capacitance characteristics, the touch algorithm can determine three rotation states: (A Pad), (B Pad), or (C Pad), representing the user's finger connection to A Pad, B Pad, and C Pad, respectively. In addition,

the prior knob supports the pressure function. As shown in Fig 4(b), when the user presses down the knob, all three conductive electrodes simultaneously contact the user's finger through the shorter contacts, rotary wheel, and conductive ring. In this condition, C_{KA} , C_{KB} , and C_{KC} will all exhibit non-zero capacitance signals, allowing the touch algorithm to determine the pressure state: (A Pad+B Pad+C Pad).

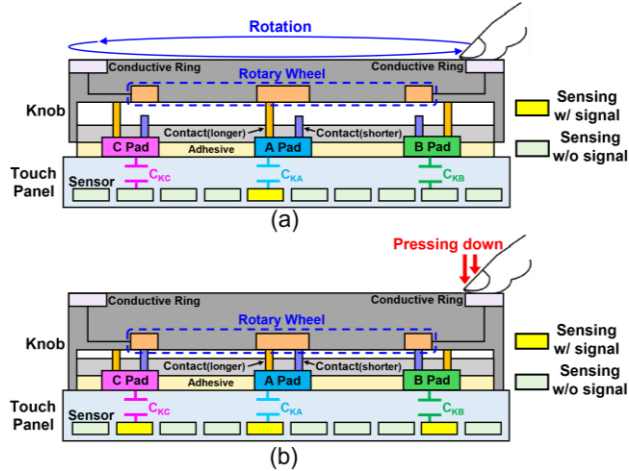


Figure 4. The prior knob structure with (a) Rotation state = (A Pad) (b) Pressure state = (A Pad+B Pad+C Pad)

Based on the working principle of the prior knob, the sequences of the knob's rotation state and pressure state are shown in Fig 5(a) and Fig. 5(b), respectively. The rotation states (A Pad), (B Pad), and (C Pad) alternate periodically during rotation, with the transition order being reversed for clockwise and counterclockwise rotation. This design ensures that regardless of the current rotation state, pressing down the knob always results in the same pressure state (A Pad+B Pad+C Pad). However, this pressure mechanism has a limitation: if the knob is rotated while being pressed down, the touch algorithm cannot distinguish this action, as the pressure state always results in all three electrodes being simultaneously connected. This limits the functionalities that can be achieved with the prior knob.

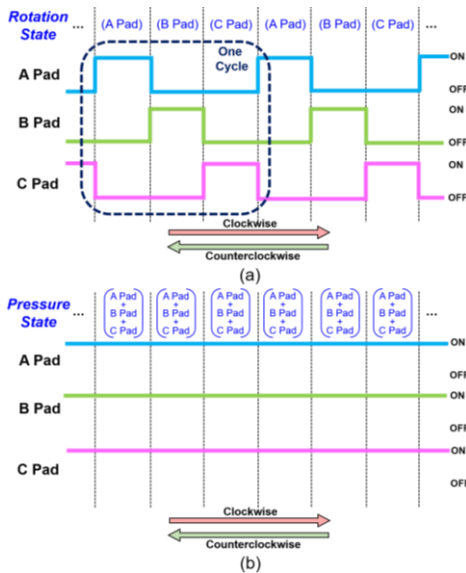


Figure 5. (a) The rotation state sequence (b) The pressure state sequence of the prior knob

(b) The Innovative Knob Design

To achieve the press-and-rotate function, we propose an innovative knob design. The innovative knob structure, shown in Fig. 6(a), still features three conductive electrodes at the bottom fixed onto the touch panel. These three conductive electrodes named A Pad, B Pad, and C Pad, form capacitances with the touch sensors under them, which are denoted as C_{KA}' , C_{KB}' and C_{KC}' respectively.

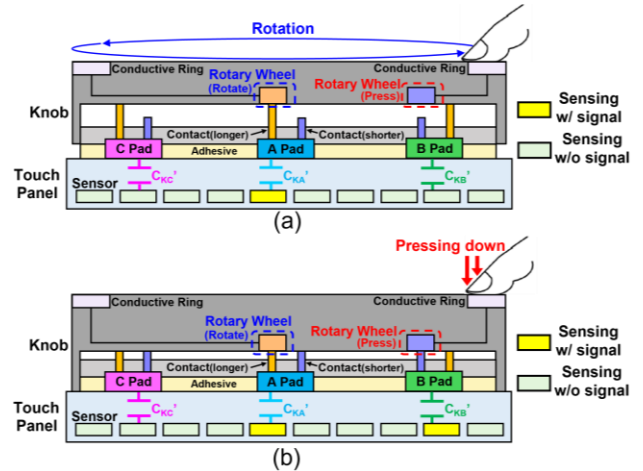


Figure 6. The innovative knob structure with (a) Rotation state = (A Pad) (b) Pressure state = (A Pad+B Pad)

The key difference between the innovative knob and the prior knob lies in the internal mechanism, particularly in the rotary wheel design. The new design features two rotary wheel components: one for rotation and one for pressure. The rotary wheel for rotation is fundamentally the same as that of the prior knob, ensuring that the rotation behavior follows the same sequence shown in Fig. 5(a). Only one electrode connects to the user's finger at any given rotation state, resulting in only one of C_{KA}' , C_{KB}' , or C_{KC}' having a non-zero capacitance signal, as shown in the signal transitions of the rotation states in Fig. 7.

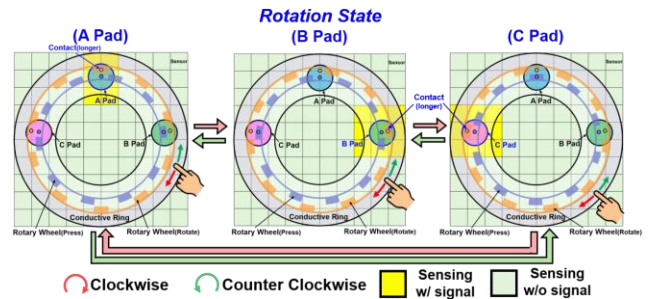


Figure 7. The signal transition of the rotation state with the innovative knob

A notable feature of the innovative knob design is the rotary wheel for pressure. The gears of this wheel are offset by one-third of a cycle relative to those of the rotary wheel for rotation. This one-third cycle offset results in an angular difference $\Delta\theta_{Wheel}$ equivalent to one step of the knob's detents N , as given by Equation (2).

$$\Delta\theta_{Wheel} = 360^\circ / N \quad (2)$$

As a result, variations occur in the switching logic corresponding to the three electrodes when the knob is pressed. The pressure state sequence of the innovative knob is shown in Fig. 8.

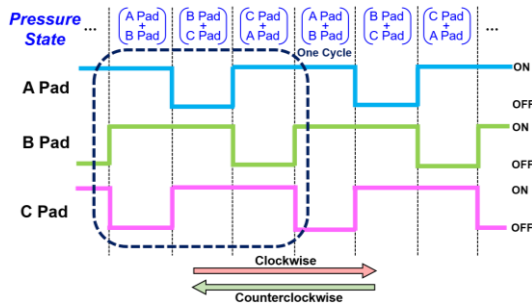


Figure 8. The pressure state sequence of the innovative knob

As shown in Fig. 6(b), only two electrodes simultaneously contact the user's finger under pressure. One electrode makes contact via the longer contact, the rotary wheel for rotation, and the conductive ring; the other electrode via the shorter contact, the rotary wheel for pressure, and the conductive ring. Moreover, as the knob is rotated clockwise or counterclockwise while being pressed down, the sequence of the two connected electrodes changes periodically. As shown in Fig. 9, this sequence allows the touch sensors under two of the three conductive electrodes to detect capacitance changes, where two of C_{KA} , C_{KB} , and C_{KC} exhibit non-zero capacitance signals. This results in three pressure states: (A Pad+B Pad), (B Pad+C Pad), and (C Pad+A Pad). This enables the touch algorithm to determine the pressure state and report it to the automotive host system to implement functions that require press-and-rotate behavior.

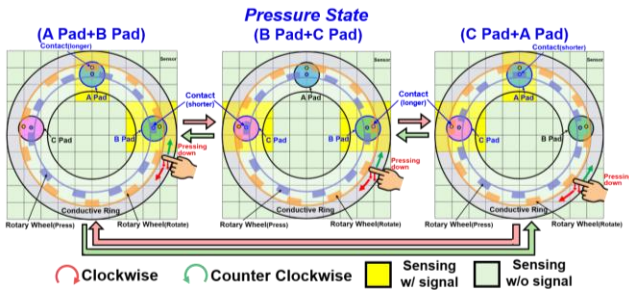


Figure 9. The signal transition of the pressure state with the innovative knob

(c) Positioning of the Innovative Knob

As automotive display panels continue to increase in size and to enable both the driver and the passenger to easily utilize the touch panel, we believe that future designs will require more than a single knob. This may potentially increase the number of required knobs to two or more. However, the current knob has a diameter of approximately 40 to 50 mm. Adding more knobs increases the occupied area of the panel, which impacts the user's experience. Thus, the innovative knob design can be positioned within the active area, as shown in Fig. 10(a), or at the edge of the active area to accommodate two or more knobs, as shown in Fig. 10(b). However, the in-cell touch LCD rely on touch sensors within the active area for capacitive detection. Therefore, if the knob's conductive electrodes are located outside the active area, the capacitive signals become too weak, potentially causing the rotation or pressure state to be undetected or misinterpreted. To solve the challenge mentioned above, the innovative knob adjusts the positions of the conductive electrodes by moving the A Pad, B Pad, and C Pad into the active area. It is necessary to ensure that the rotation and pressure sequences of A Pad, B Pad, and C Pad keep the original logic.

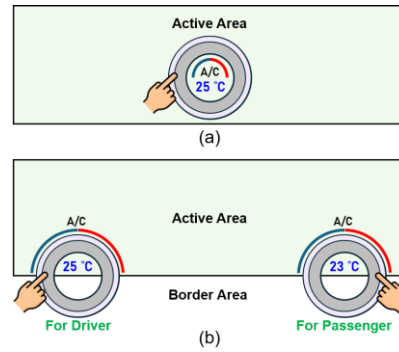


Figure 10. (a) Single knob attached within the active area (b) Two knobs attached at the edge of the active area

Therefore, the relative angular differences between the three conductive pads need to be considered. If the knob has N detents and the angle of A Pad θ_A is defined as 0 degrees, with clockwise rotation as positive and counterclockwise as negative, the angles of B Pad θ_B and C Pad θ_C are given by Equation (3) and Equation (4) respectively:

$$\theta_B = + \left(\frac{360^\circ}{N} \right) \times (3k + 1) \tag{3}$$

$$\theta_C = - \left(\frac{360^\circ}{N} \right) \times (3k + 1) \tag{4}$$

where k is any given integer. These two angles represent the angles of the contacts between A Pad and B Pad, and between A Pad and C Pad, respectively. By adjusting the angles of the contacts, the original switching sequence can be maintained. Fig. 11 illustrates an example where the innovative knob has an outer diameter of 50 mm, an inner diameter of 25 mm, and 30 detents. According to the Equation (3) and Equation (4), the angles of B Pad and C Pad are adjusted to +84 degrees and -84 degrees, respectively. In this configuration, all three conductive electrodes can be concentrated in the upper half of the knob. When the knob is attached at the edge of the active area of an in-cell touch LCD, the knob functions can operate normally while minimizing the display area occupied by the knob. Additionally, the hollow central area of the knob can be utilized to display necessary information.

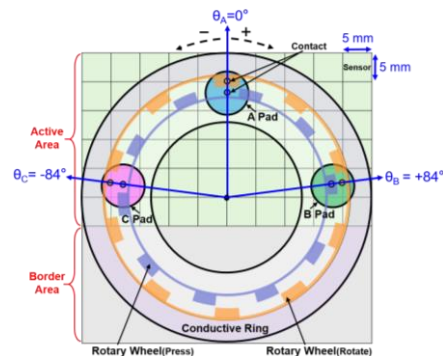


Figure 11. The innovative knob positioning example at the edge of the active area

3. Simulation Result

The simulation model is based on the innovative knob attached at the edge of an in-cell touch LCD, which has 12x6 touch sensors, each with a size of 5 mm x 5 mm. The panel stack-up is shown in Table 1. In this simulation, the innovative knob has an outer diameter of 50 mm, an inner diameter of 25 mm, and a height of 10 mm, with 30 detents in a full rotation.

In addition, the conductive electrodes A Pad, B Pad, and C Pad at the knob's bottom all have a diameter of 7 mm and are located within the active area. To simulate the user's knob manipulation, two 8phi slugs are placed on the 4 mm wide conductive ring of the knob, as shown in Fig. 12.

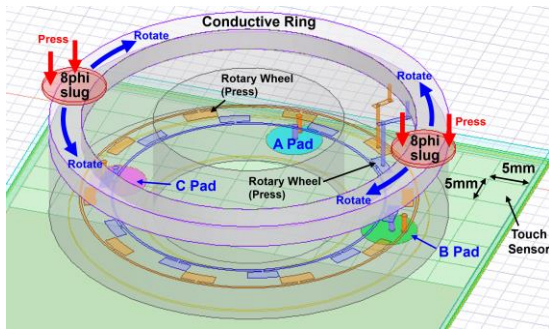


Figure 12. The simulation model of the innovative knob

With each step of rotation in either the clockwise or counterclockwise direction, a single capacitance peak signal is detected by the touch sensor under the conductive electrode in contact with the finger. Subsequently, when the knob is pressed down, the previous signal characteristic changes to two capacitance peak signals detected simultaneously by the touch sensors under the conductive electrodes in contact with the finger. Additionally, rotating the knob while pressing down results in the positions of the two signal peaks changing to another distribution pattern. These simulation signal distribution patterns are all shown in Fig. 13. The simulation results demonstrate that the innovative knob produces distinct signal distributions for rotation, pressure, and press-and-rotate functions, enabling the touch algorithm to accurately interpret inputs and report them to the automotive host system.

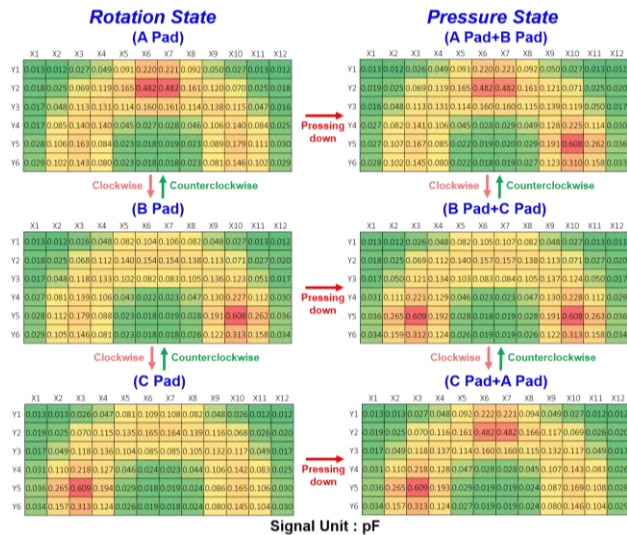


Figure 13. The innovative knob signal simulation results

Table 1. The panel stack-up of the simulation

Layer	Dielectric constant	Thickness (mm)
Adhesive	3	0.25
Cover Glass (CG)	7	1.3
OCA	3.5	0.25
Polarizer (POL)	3	0.1
CF Glass	5.7	0.2
Touch Sensor (Size= 5mm x 5mm)		
TFT Glass	5.7	0.2

4. Conclusions

This paper presents an innovative capacitive knob design for automotive in-cell touch LCDs. Compared to the prior knob design, it demonstrates the feasibility of implementing the press-and-rotate function through its structural improvements. Moreover, it provides versatile positioning for automotive in-cell touch LCDs by adjusting the conductive electrode locations, as confirmed by the capacitance simulation results. Fig. 14 shows the actual demonstration of the knob attached at the edge of the in-cell touch LCD with Novatek automotive TDDI.

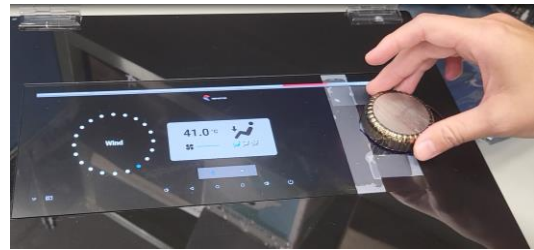


Figure 14. The innovative knob signal simulation results

5. References

- Rogers WA, Fisk AD, McLaughlin AC, Pak R. Touch a screen or turn a knob: Choosing the best device for the job. *Human Factors: The Journal of the Human Factors and Ergonomics Society*. 2005;47(2):271-88. doi:10.1518/0018720054679452
- Knob-on-display™ (Kod™) touch Controller family - microchip technology. [Internet]. [cited 2024 Nov 21]. Available from: <https://www.microchip.com/en-us/products/touch-and-gesture/maxtouch-touchscreen-controllers/kod-family>
- Fong K, Hirakawa T, Li R, Tu J. 96-3: Invited Paper: Next-Gen Interactions: Creative Sensing Solutions for Automotive Capacitive Knobs on Displays. *SID Symposium Digest of Technical Papers*. 2024 Jun;55(1):1359–62.
- Chang YC, Lai CC, Lin CC. 96-2: A Novel Capacitive Knob Design with Finger Detection using Automotive In-Cell Touch LCD. *SID Symposium Digest of Technical Papers*. 2024 Jun 1;55(1):1355–8.