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Research paper

A Study on the Method of Detecting the Ghost-Key Phenomenon of Rubber Contact Switch Type Remote Controller for the Smart-TV

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Abstract

Background/Objectives: In this paper, ghost-key phenomenon detection method was proposed for rubber contact switch type remote controller of smart-TV.
Methods/Statistical analysis: The principle of ghost-key phenomenon is analyzed when the switches are pressed simultaneously. The requirements of pull-up resistor ratio are obtained by case study with a circuit modeling. The proposed method is an optimized design that the switch has the greatest voltage difference between the normal state and the ghost-key state.
Findings: In order to verify the proposed method, a remote controller with a rubber contact switch and a microcontroller were set up and tested based on theoretical values. The performance of proposed method was verified that the voltage is apparently distinguishes between normal state and ghost-key state. As a result, analog-to-digital conversion of the microcontroller can be used to detect and remove the ghost-key.
Improvements/Applications: The proposed method can overcome limitations of other equipment with rubber contact switch. Therefore, the application range of rubber contact switch is expected to be expanded.

Keywords: *ghost-key, phantom-key, dynamic scan, rubber contact, remote controller, smart-TV*

1. Introduction

Recently, electronic devices are adopted as advanced devices with various functions by virtue of computer and IT(information technology) development. For example, telephones have evolved into smart-phones with the addition of high-performance computers and high-speed wireless communication technology. Also, the television that transmitted video and sound remotely evolved into smart-TV with built-in computer and internet. This trend is accelerating with the IoT(Internet of things) technology[1,2]. As electronic devices evolve, input devices have also been advanced, the smart-phone uses a high-performance touch-screen device to detect the user's hand movements and receive and process various instructions accordingly[3]. The simple remote controller of the past changed to perform the same function as the keyboard as shown in figure 1. The conventional computer keyboard uses dynamic scanning to detect that multiple buttons are pressed due to limited number of microcontroller_ ports[4,5]. However, ghost-key phenomenon occurs when three or more switches are pressed at the same time due to the dynamic scanning[6].

Since mechanical switches are attached to the PCB (printed circuit board) in a mechanical keyboard, it can prevent ghost-key phenomenon by using a diode[6]. Also, Shun-Pin Lin[7] proposed a method to detect ghost-key using a series resistor and comparator inside the switch. Membrane type keyboard is widely used because it is inexpensive and advantageous for mass production[8]. However, it is difficult to attach a device such as a diode due to a film type switch. For this reason, Paul H. Dietz et al.[9] proposed ghost-key detection method by placing a conductor on the membrane surface as a zigzag to generate resistance. Also, Lee[10] applied an additional coating to the membrane switch contact and contact voltage is detected to remove the ghost-key.

In this way, various methods have been proposed to eliminate the ghost-key in mechanical type keyboards and membrane type keyboards[11,12]. On the other hand, the rubber contact switch, which is used for a small number of switches and hardly pressing at the same time, rarely causes ghost-key. Therefore, few studies have been carried out to detect ghost key on the rubber contact switch. Recently, the use of rubber contact switches, such as the smart-TV remote controllers, tends to expand, and ghost-key is inevitable when rubber contact switches are used like a general computer keyboard. For example, if a remote controller is used to play a game as shown in figure 1, the application is restricted by ghost-key. The rubber contact switches are designed to be dense with a limited area. Therefore, the addition of diodes or the additional coatings to the rubber contacts is disadvantageous in terms of size and cost.

Figure 1: Remote controller with rubber contact switches for Smart-TV

In this paper, a method to remove ghost-key for the remote controller configured with rubber contact switch is proposed. In order to distinguish the normal-key and ghost-key clearly, all the parameters are determined by optimization with circuit analysis.

2. Dynamic Scanning and Rubber Contact Switch

2.1. Dynamic Scanning

In the computer keyboard and the remote controller, dynamic scanning is used to detect status of switches due to limited port of microcontroller[4,5]. In figure 2, the ports of the microcontroller are arranged in matrix form, and switches are connected to each intersection. In order to scan column Y_1, the microcontroller controls U_1 to low and the remaining columns to float. When switch of SW_{11} is pressed, X_1 line goes logical low and another lines remain to logical high by PU(pull-up resistor). The microcontroller detects input lines by controlling Y_1 to float and Y_2 to logical low to scan the next row. This series of processes can be repeated continuously to detect the status of all switches. U_1 - U_3 uses the open - collector type so that the output does not collide when switches are pressed at the same time.

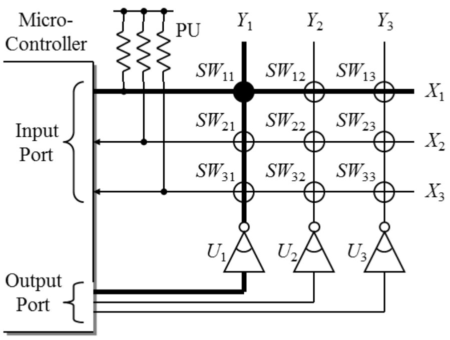


Figure 2:.The principle of dynamic scanning

2.2. Ghost-Key Phenomenon

Dynamic scanning has a problem that ghost-key occurs when a certain combination of switches are pressed simultaneously as shown in figure 3 and 4. For example, three switches are pressed simultaneously within a 2×2 array as shown in the figure 3. When the microcontroller controls to low state to scan the Y_2 column, I_1 flows through SW_{12} and the switches of X_1 are detected as pressed. Since SW_{11} is on, however, the Y_1 column is also low. X_2 is also set to low by SW_{21}, and it is detected that the SW_{22} is pressed even though it is not pressed. This is called ghost-key phenomenon, or phantom-key phenomenon[6]. Figure 4 shows that both SW_{22} and SW_{23} are detected as ghost-key by the same principle.

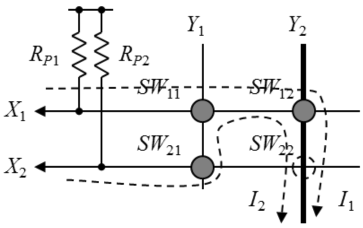


Figure 3: The current path of ghost-key phenomenon at 2 × 2 array

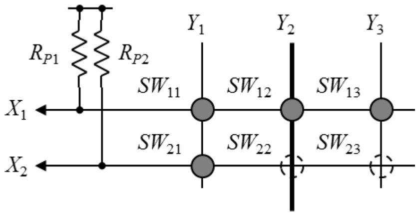


Figure 4: The condition of ghost-key appearance in 2 × 3 array

The mechanical type keyboard can prevent the ghost-key phenomenon by connecting diodes to each switch. They can block reverse current at the switches[6].

2.3. Rubber Contact Switch

In figure 5, the rubber contact switch includes that conductive rubber is attached in non-conductive rubber body. When the user presses the body, the conductive rubber contacts the contact point of the PCB and acts as a switch. Figure 6 shows components of the rubber contact switch: rubber part and PCB part. The rubber contact switch is mainly used for remote controller, calculator, game machine, electronic dictionary and toy musical instrument because of its simplicity of structure, high density and low cost. Meanwhile, adding a number of diodes or resistors to prevent ghost keys can be a relatively large cost factor.

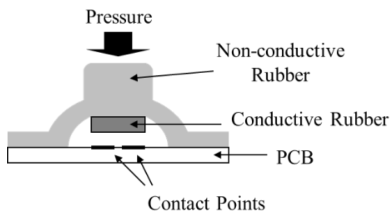


Figure 5: The structure of rubber contact switch

(a) Rubber part

(b) PCB part

Figure 6: Components of rubber contact type keyboard

3. Ghost-key detection and removal methods

3.1. Resistivity of Rubber Contact

The rubber contact switch uses a conductive rubber as a conductor, which has its own resistance[13]. It is notice that the resistance is used to detect ghost-key for the proposed method in this paper. If the resistance of conductive rubber is designed to be small, the price will increase; some resistance of conductive rubber has no choice but to be accepted. Instead, the pull-up resistor is selected as a large value and the circuit is designed so that contact resistance is negligible.

3.2. Theoretical Circuit Analysis

In a typical computer game, two direction-key and two attack-key switches are used at the same time. Therefore, the circuit is analyzed only when four switches are pressed at the same time in the case studies.

3.2.1. Analysis of 2 × 2 Array

Figure 7 shows an equivalent circuit of a 2 × 2 array considering rubber contact resistance. Also, the combination that a ghost-key phenomenon occurs (SW_{11}, SW_{12}, and SW_{21} are turned on and SW_{22} is turned off as shown in the figure 3) is analyzed. When the Y_1 column is scanned, two detection voltages V_1 and V_2 are the same as shown in figure 8(a).

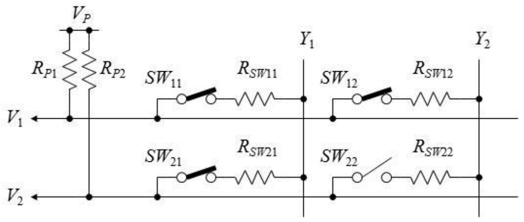
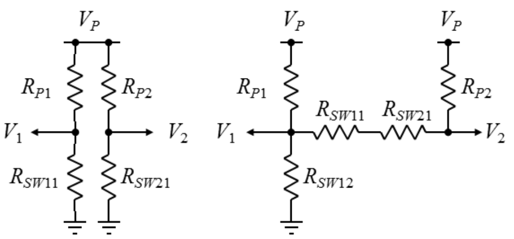


Figure 7:. Equivalent circuit of 2 × 2 array



(a) Y_1 scan **(b) Y_2 scan**

Figure 8: Equivalent circuits of each state Y_1 and Y_2

When the Y_2 column is scanned, however, the equivalent circuit is as shown in figure 8(b); the voltage of the normal-key V_1 differs from the voltage of the ghost-key V_2. The microcontroller can determine difference of voltage by analog-to-digital conversion[14].

The larger difference between the voltage V_1 and the voltage V_2, the more clearly the microcontroller can distinguish the voltage. Therefore, the optimized ratio of the pull-up resistance(R_P) and the switch contact resistance(R_{SW}), which can produce the largest voltage difference, should be determined. It is assumed that the switch contact resistances are the same and the pull-up resistances are the same. The voltage of normal key is obtained as

$$V_1 = \frac{R_{SW}}{R_{SW}+(R_P+2R_{SW})\|R_P} \cdot V_P$$

$$= \frac{2R_{SW}^2+2R_{SW}\cdot R_P}{2R_{SW}^2+4R_{SW}\cdot R_P+R_P^2} \cdot V_P \quad (1)$$

Where, V_P is pull-up voltage. The voltage of ghost-key is

$$V_2 = \frac{2R_{SW}}{2R_{SW}+R_P} \cdot (V_P - V_1) + V_1$$

$$= \frac{2R_{SW}^2+4R_{SW}\cdot R_P}{2R_{SW}^2+4R_{SW}\cdot R_P+R_P^2} \cdot V_P \quad (2)$$

Given the V_1 and V_2, the difference of voltage can be calculated from equation (1) and (2), i.e.,

$$V_2 - V_1 = \frac{2R_{SW}\cdot R_P}{2R_{SW}^2+4R_{SW}\cdot R_P+R_P^2} \cdot V_P \quad (3)$$

The voltage difference according to the ratio of R_{SW} to R_P based on equation (3) has maximum value as shown in figure 9. The solution of the maximum value of equation (3) can be found by setting the partial derivative of equation (3) with respect to R_P to zero, i.e.

$$R_P = \sqrt{2} \cdot R_{SW} \quad (4)$$

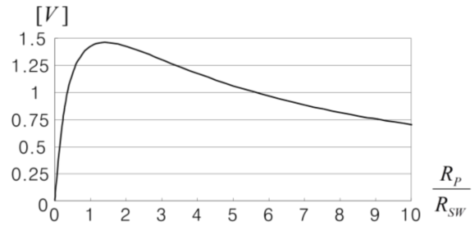


Figure 9: Voltage difference by ratio of resistances

3.2.2. Analysis of 2 × 3 Arrays

When the four switches are pressed simultaneously in a 3 × 2 array as shown in the figure 4, the equivalent circuit is the same as the figure 8(b) so that the equation (4) can be applied.

3.2.3. Analysis of 3 × 2 Arrays

When the four switches are pressed simultaneously in a 3 × 2 array as shown in figure 10, the equivalent circuit can be represented as shown in figure 11.

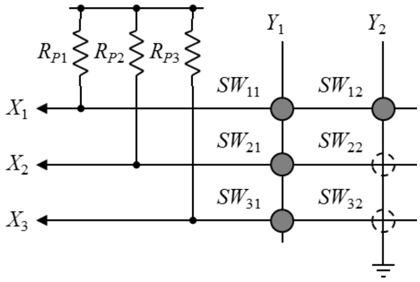


Figure 10: The condition of ghost-key appearance in 3 × 2 array

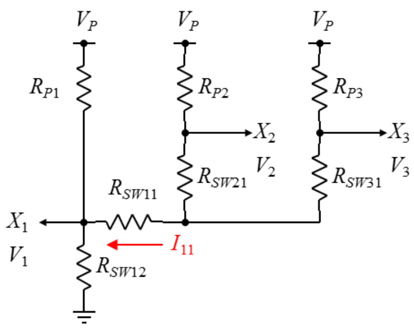


Figure 11: Equivalent circuit of 3 × 2 array

In figure 11, the voltage of normal-key V_1 is

$$V_1 = \frac{R_{SW}}{R_{SW}+\{(R_P+R_{SW})/2+R_{SW}\}\|R_P} \cdot V_P$$

$$= \frac{3R_{SW}^2+3R_{SW}\cdot R_P}{3R_{SW}^2+6R_{SW}\cdot R_P+R_P^2} \cdot V_P \quad (5)$$

The current I_{11} passing through R_{sw11} in the figure 11 can be expressed by

$$I_1 = \frac{V_P - V_1}{(R_P+R_{SW})/2+2R_{SW}} = \frac{2V_P - 2V_1}{R_P+3R_{SW}} \quad (6)$$

The voltage of ghost-key V_2 can be calculated from equation (5) and (6), i.e.,

$$V_2 = V_1 + R_{SW}\cdot I_1 + R_{SW}\cdot \frac{I_1}{2} = V_1 + \frac{3}{2}R_{SW}\cdot I_1 \quad (7)$$

Substitution equation (6) into equation (7) yields

$$V_2 - V_1 = \frac{3R_{SW} \cdot V_P - 3R_{SW} \cdot V_1}{3R_{SW} + R_P} \quad (8)$$

Substitution equation (5) into equation (8) yields

$$V_2 - V_1 = \frac{3R_{SW} \cdot R_P}{3R_{SW}^2 + 6R_{SW} \cdot R_P + R_P^2} \cdot V_P \quad (9)$$

The solution of the maximum value of equation (9) can be found by setting the partial derivative of equation (9) with respect to R_P to zero, i.e.

$$R_P = \sqrt{3} \cdot R_{SW} \quad (10)$$

3.3. Optimized Condition Selection by Simulation Study

In summary, the maximum voltage difference can be obtained when the ratio is from equation (4) in 2 × 2 and 2 × 3 arrays, and from equation(10) in 3 × 2 arrays. In order to apply only one of the conditions equation (4) and (10) to the switches of the entire keyboard, optimized conditions should be determined. They are shown in table 1 based on equation (3) and (9). It is assumed that the pull-up voltage V_P is +5V.

Table 1: Voltage difference by combination of switch type and resistance ratio

Condition / Array	$R_P = \sqrt{2} \cdot R_{SW}$	$R_P = \sqrt{3} \cdot R_{SW}$
2 × 2	1.464 [*V*]	1.453 [*V*] ← **worst**
2 × 3	1.464 [*V*]	1.453 [*V*]
3 × 2	1.573 [*V*]	1.585 [*V*] ← **best**

The condition of equation (10) has the largest voltage difference when applied to a 3 × 2 array, but the smallest value in a 2 × 2 array. Meanwhile, the condition of equation (4) is smaller than the maximum value of the condition of equation (10), but is larger than the minimum value of it so that it is more advantageous to apply the condition of equation (4).

Table 2 shows the voltage and voltage differences for condition of equation (4) as a result of PSPICE simulation. The slight difference between the three decimal places in table 1 and table 2 is caused by the resistor value input only to 4 decimal places in PSPICE.

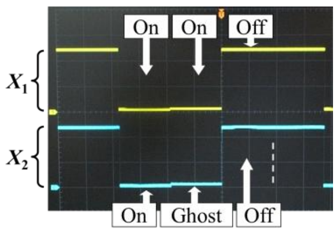
Table 2: Result of simulations at condition of equation(4)

Status / Array	Norm.(V_1) [*V*]	Ghost(V_2) [*V*]	Diff. [*V*]
single	2.071	-	-
2 × 2	2.500	3.965	1.465
2 × 3	2.500	3.965	1.465
3 × 2	2.688	4.263	1.575

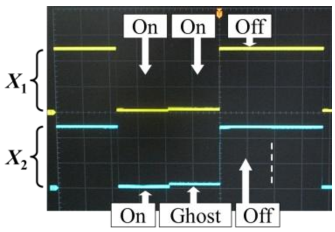
3.4. Experimental Results

In order to verify the effectiveness of the proposed ghost-key detection method, the experimental circuit was setup by modifying the rubber contact type remote controller as shown in figure 12. The resistance of the rubber contact is about 1.1$K\Omega$ and the pull-up resistor is 1.5$K\Omega$ based on the equation(4). In general, the pull-up resistors of remote controller use a 100 times greater resistance (i.e., R_p = 110$K\Omega$) of the rubber contact resistance. Figure 13 shows the X_1 and X_2 rows voltage of a conventional remote controller circuit (i.e., figure 3 and 4). The difference between the switch on state and the ghost state is too small to detect the ghost-key as shown in the figure 13. In contrast, figure 14 shows the result of applying the proposed pull-up resistor based on equation (4); In both 2 × 2 and 3 × 2 arrays, the voltage difference between the normally on state and the ghost state can be clearly distinguished. Table 3 shows the measured voltages in each case study and is shown in figure 15. The figure 15 shows that the theoretical results and experimental results are almost identical. Experimental results verify that ghost-key can be detected and removed by detecting the voltage using the analog-to-digital conversion port.

Figure 12: Experimental setup of ghost-key detection method in a remote controller

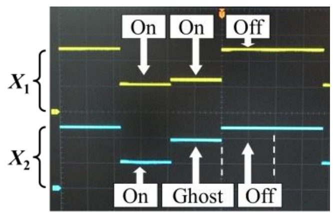


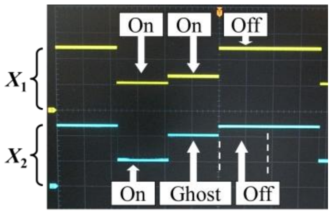
(a) 2 × 2, 2 × 3 array



(b) 3 × 2 array

Figure 13: Waveforms of experimental result at R_p = 110$K\Omega$(Volt/div = 2V, Time/Div = 200μS)





(a) 2 × 2, 2 × 3 array **(b) 3 × 2 array**

Figure 14: Waveforms of experimental result at R_p = 1.5$K\Omega$(Volt/div = 2V, Time/Div = 200μS)

Table 3: Experimental results

R_P [$K\Omega$]	Status / Array	Norm.(V_1) [V]	Ghost(V_2) [V]	Diff. [V]
110	single	2.071	-	-
	2 × 2	2.500	3.965	1.465
	2 × 3	2.500	3.965	1.465
	3 × 2	2.688	4.263	1.575
1.5	single	2.1	-	-
	2 × 2	2.5	3.95	1.45
	2 × 3	2.5	3.95	1.45
	3 × 2	2.65	4.25	1.6

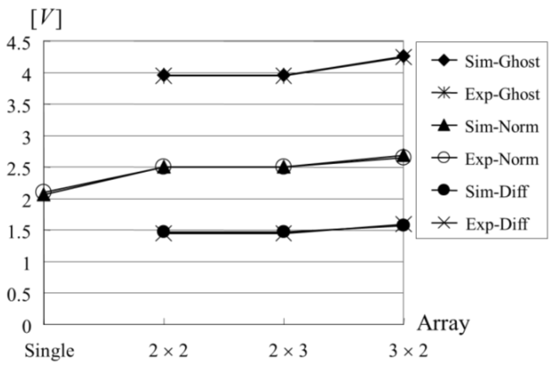


Figure 15: Simulation and experimental results of detected voltage according to key combinations

4. Conclusion

In this paper, ghost-key phenomenon detection method was proposed for rubber contact switch type remote controller of smart-TV. The principle of ghost-key phenomenon is analyzed when the switches are pressed simultaneously. The requirements of pull-up resistor ratio are obtained by case study with a circuit modeling. The proposed method is an optimized design that the switch has the greatest voltage difference between the normal state and the ghost-key state.

In order to verify the proposed method, a remote controller with a rubber contact switch and a microcontroller were set up and tested based on theoretical values. The performance of proposed method was verified that the voltage is apparently distinguishes between normal state and ghost-key state. As a result, analog-to-digital conversion of the microcontroller can be used to detect and remove the ghost-key.

The proposed method can overcome limitations of other equipment with rubber contact switch. Therefore, the application range of rubber contact switch is expected to be expanded.

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