Iranian Journal of Fuzzy Systems

Volume 21, Number 5, (2024), pp. 121-132

Original paper

Design and realization of a random display system of a virtual keyboard based on a fuzzy system

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Abstract

Security and confidentiality of our information such as access codes bank or postal accounts are becoming more and more important to protect against espionage by foreigners. There are several researches to improve the security of the user's personal information when entering the password, or saving, ... etc. The objective of this paper is to create a novel virtual keyboard display system based on a random display algorithm, in order to have a keyboard with random combinations of the virtual display matrix. This work focuses on the introduction of fuzzy systems mixed with the random number generation. Fuzzy systems use the values of the pressure forces exerted by the user or the operator on the virtual keyboard touchscreen as inputs to the fuzzy systems. The fuzzy system is designed by using the time-varying fuzzy sets. We use the "modulo operator" algorithm to generate a random integer. For the realization, we use a microcontroller (ESP8266 node MCU.V3 microcontroller) and the touchscreen (ili9341) to display a 4X4 numeric matrix to enter a standard four-digit code.

Keywords: Fuzzy systems, random algorithms, PIN code, keyboard systems, time-varying fuzzy sets.

1 Introduction

With the advent of digital technologies supported by information and communication technologies, a variety of services have appeared on the Internet, particularly for monetary cards (Entering a secret code or password, Generating a PIN code, ...). These services are increasingly billed electronically, accompanied by postcards or bankcards, and access to personal accounts for collection or delivery. Therefore, the security of these operations becomes a requirement, starting with the keyboard system [7, 9, 14, 19, 21, 25], the software algorithm [6, 8] , the encryption of information, ... and hardware device as ATM [23]. The Automated Teller Machines (ATM) [23], either postal or banking, use a mechanical keyboard of 4X3 or 4X4 formats. Particularly this type of system doore security for the users to enter their PIN code easily, or to secure their personal information during its use and to limit the theft of personal information. In this paper, we will present a new design and implementation of a random display system for a virtual keyboard, based mainly on a fuzzy logic system and an algorithm [4, 13, 15, 16, 20, 22] for generating a random number [3, 11, 12, 18] . The proposed structure is composed of five blocks: Virtual keyboard block, fuzzy system block, block of the random coordes not provide minates (I, J) generator, block of the random display matrix development (size 4X4), and the block of the new display matrix. The fuzzy system uses the pressure forces of pressing the tactile keys as inputs to the fuzzy system as well as it uses time-varying fuzzy sets [13, 26, 27, 28] . In this achievement, we will focus on the implementation of a random display system to enter a 04-digit PIN code. The realization of this design is based on the microcontroller ESP82266-MCU V3 [5] and touch screen ili9341 [2]. The paper is organized as follows, objective of the project is defined in section 2, and sections 3 and 4 discusses the design and the realization respectively of a random display system of a virtual keyboard. Section 5 presents the realization results. Finally, a conclusion is given in Section 6.

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Received: March 2024; Revised: November 2024; Accepted: November 2024.
https://doi.org/10.22111/ijfs.2024.48292.8495

2 Objective of the project

The objective of this paper is to create a virtual touch keyboard display system, which can be placed in bank or postal ATMs (software and hardware parts) [23], to install it on their web pages (software part) [24], or use it as a PIN code generator for a new electronic payment card, ... etc. The numbers or the symbols of the virtual keyboard, which constitutes the display matrix, changes randomly after each use or after each cancellation or after leaving the operation. The goal of changing the position of the numbers constituting the virtual touch keyboard is to limit the theft of the secret code [1, 17]. Which is likely to be stolen by a person behind the user when entering their personal information. Where they can know the state of the client's support on the keyboard and deduce the secret code accompanying the position of the numbers and symbols in relation to the normal keyboard known to all. Also in the case of electronic piracy, where there are virus programs which hack the press position or track how the keyboard changes keys [10].

Figure 1: ATM Algerian Example : Postal and Banking ATM.

In this work, we propose one of solutions for the security of user's personal information, where we suggest a new design and realization of a random display system of a virtual keyboard based mainly on a Mamdani fuzzy logic system [4, 13, 15, 16, 20, 22].

3 Design a random display system of a virtual keyboard

The contribution of this work is to propose a new design for a random display of a virtual keyboard. This design is mainly based on a fuzzy system [4, 13, 15, 16, 20, 21, 22] merged with the generation of classical random numbers [3, 11, 12, 18]. The diagram in the following figure represents the structure of the functional blocks of the proposed design.

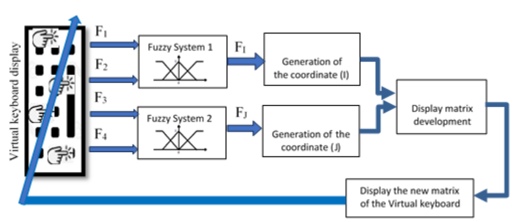

Figure 2: Design a random display system structure of virtual keyboard.

with:

- (F_1, F_2) and (F_3, F_4): represents the pressure forces exerted by the user on the touchscreen. The touchscreen device generates the values of theses pressure forces [29].
- Each pressure force corresponds to a number of the PIN code, overally there are four forces (F_1, F_2) and (F_3, F_4) for four numbers (N_1, N_2) and (N_3, N_4) .
- F_I, F_J: represents the output of the fuzzy system.
- (I, J): are the coordinate of the display matrix "MD", the number "I" represents the row's position and the "J" represents the column's position.

This proposed structure of the display system is composed for five blocks: Virtual Keyboard Block, Fuzzy System Block, Block of the Random Coordinates (I, J) Generator, Block of the Random Display Matrix Development (4X4), and the Block of the New Display Matrix.

3.1 Virtual keyboard block

This block represent a main HMI (Human Machine Interface) interface to be use by any user or operator by asking him to enter the secret code in complete safety and tranquility via a touch screen, formed by a matrix of 4X4 keys. By offering him "Confirmation" buttons, if the code is correct, he will be authorize to perform the remaining steps. If the code is incorrect, the user will have two offering possibilities to enter the code again after the confirmation by the "Try Again" button or key, else a message appears "Your card is captured". Another button called "Cancel" is available to exit the operation. The function of this block is given in this algorithm 1:

Algorithm 1 Procedure MAIN INTERFACE

```
Load the initial matrix;    (*Initialization of the first virtual keyboard matrix*)
Label : Label1
Call Procedure : Main interface                    (*Not detailed in this work*)
NU ⇐ 0;                    (* parameters Initialization, NU : Number of attempts*)
NK ⇐ 0;               (*parameters Initialization: NK : Number of pressed keys*)
Read the pressed Button
if Withdrawal = True then
    Label : Label2
    Call Procedure : Read PIN Code
    if PINcode = Correct then
        Message ⇐ "Code correct";
        Call procedure:"Continue the operation tasks";(*not detailed in this work*)
        Call procedure:"Remove your card" ;          (* not detailed in this work*)
        Message ⇐"Please remove your card";               (* end of the operation*)
        goto Label1;
    else
        Message ⇐ "Code incorrect" :  "Try again (T) or Cancel (C)";
        Label : Label3
        Read "Try again (T) " or "Cancel (C)";
        if T = True then
            NU ⇐ NU + 1 ;                  (* the number of utilization (attempts)*)
            if NU ≥ 3 then
                Call procedure:"Your card is Captured";(*not detailed in this work*)
                Message ⇐ "Your card is Captured";     (* end of the operation*)
                T ⇐ False; goto Label1;
            else
                goto Label2;
            end if;
        else
            if C = True then
                Call procedure: "Remove your card" ;     (*not detailed in this work*)
                Message ⇐"Please remove your card";        (*end of the operation*)
                C ⇐ False; goto Label1;
            else
                goto Label3;
            end if;
        end if;
    end if;
else
    Call procedures (Balance inquiry, Transfer, ...); (* not detailed in this work*)
end if;
End;
```

The "Main interface : with Select Language (Fr, Ar, En),...", "Remove your card", "Your card is captured", "Continue the operation tasks", "Balance inquiry, Transfer, ..." are not defined in this work. In this work, we focus essentially on the procedure "Read PIN Code" defined by the following algorithm 2 to show the contribution of this paper:

Algorithm 2 Procedure Read PIN code

Display the New matrix of the virtual keyboard (* $M_D(i)$*)
Label : Label4
Read the pressed key
Read the pressure value of the corresponding touch key pressed; (* F_i, i=1..4*)
$NK \Leftarrow NK + 1$;
if $NK \leq 4$ **then** (*a standard 4-digit code*)
    Call procedure : Fuzzy system procedure; (* see block fuzzy system : F_I, F_J*)
    Call procedure : Generation of the random coordinates (I, J);(*see block: Random number generation: (I, J)*)
    Call procedure : Display matrix development; (* see algorithm 3 : $M_D(i+1)$*)
    $NK \Leftarrow 0$;
else
    Goto Label4;
end if;
end;

To enter the PIN code, this algorithm does not offer the possibility of deleting a number or the last number, which seems false using Backspace key. In general, validating the entry of a PIN code using the OK (Enter) key is optional. For other procedures not developed in this paper, if it requires a display of a virtual keyboard, the procedure of the virtual keyboard display matrix is calculated in the same way, all these propositions are used to enhance the security.

3.2 Fuzzy system block

The generation of the random display matrix (4x4) is designed using two subsystems, which are based on Mamdani fuzzy system; whose fuzzy sets vary in time [13],[26, 27, 28]. The two fuzzy sub-systems (figure 2) use the pressure forces on the keys of the touchscreen as inputs of the fuzzy system (F_1, F_2) and (F_3, F_4) respectively (random numbers), to generate the fuzzy systems outputs (F_I and F_J) (random numbers). The fuzzy systems inputs are randomly dependent on the pressing forces of the user's fingers. The proposed fuzzy system block is characterized by : Universe of discourse, Membership functions, Fuzzy rules, Fuzzification, Defuzzification and Time-varying fuzzy sets.

3.2.1 Universe of discourse

The universe of discourse represents the range of values of the pressure forces variables, which are dependent on the physical characteristics of the touchscreen, the model used theoretically has the range U=[0, 4096] [2, 29], for our use, we chose to reduce this range to [100, 2600]. These two boundary points of the range were determined experimentally because it is impossible to reach the theoretical maximum force. Experimentally, it would require hitting (pressing) the screen very hard (risk of breaking the screen) to reach the theoretical maximum! Similarly, the minimum corresponds to no touch at all.

3.2.2 Membership functions

For the fuzzy system, each linguistic input variable (F_1, F_2) or (F_3, F_4) respectively, is characterized by the three linguistic values (Small, Medium, Big) in triangular form, represented by the figure 3.

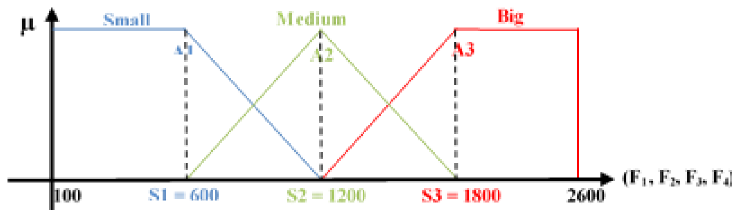

Figure 3: Fuzzy sets of inputs variables (F_1, F_2) or (F_3, F_4).

In addition, the linguistics outputs variables (F_I, F_J) have the same characteristics, three linguistic values (Low, Middle, High) in triangular form, figure 4.

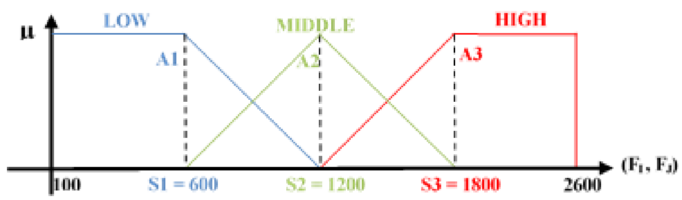

Figure 4: Fuzzy sets of outputs variables (F_I, F_J).

3.2.3 Fuzzy rules

For computing the outputs truth values, we used the fuzzy rules illustrate in the following table :

Table 1: Fuzzy rules corresponding of the two fuzzy systems

Column 1	Small(F_1, F_3)	Medium (F_1, F_3)	Big (F_1, F_3)
Small (F_2, F_4)	Low	Low	Middle
Medium (F_2, F_4)	Low	Middle	High
Big (F_2, F_4)	Middle	High	High

3.2.4 Fuzzification

The fuzzification is to translate input into truth-values, to calculate the membership degrees we use the following classical formula [20, 22, 27]:

$$\mu(x) = max(min((\frac{x - S1}{S2 - S1}, 1, \frac{S3 - x}{S3 - S2}), 0)). \tag{1}$$

3.2.5 Defuzzification

To transfer the truth-values into output we use the centroid defuzzification, assuming that we are using the center of mass defuzzification method [20, 22, 27]:

$$Z = \frac{\sum_{j=1}^{q} Z_{outj}.\mu_c(Z_j)}{\sum_{j=1}^{q} .\mu_c(Z_j)}, q = 3, j = 1...3. \tag{2}$$

where Z is the center of mass and μ_c is the membership in class c at value Z_j.

3.2.6 Time-varying fuzzy sets

In our case, the fuzzy sets used consist of three linguistic values Small, Medium, Big. The initial ranges of these linguistic values are chosen to be equal (balanced), so as not to favor one linguistic value over another. The Mamdani fuzzy system used is subject to time-varying fuzzy sets [26, 27, 28]. The basic principle of these time-varying fuzzy sets is that all kernel points Support points (S1, S2, S3) and Corner points (A1, A2, A3) of the fuzzy sets move randomly and horizontally to the left and right across the entire universe of discourse D (although they could also move up and down, which was not considered in this work). The extreme left and right kernel points of the universe remain fixed for all time, as illustrated in the following figures:

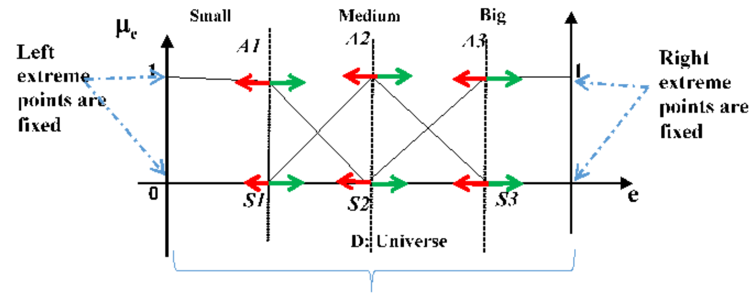

Figure 5: Design of the time-varying fuzzy sets based on Mamdani-type.

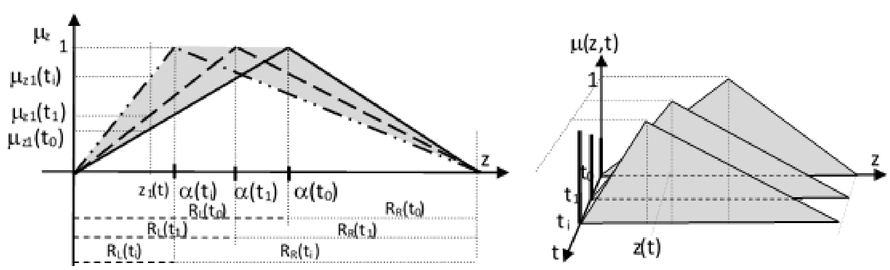

Figure 6: Triangular type of time-varying fuzzy set (2D, 3D).

The movement of the kernel points is ensured using a function f(z) (to be determined (type and parameters)) and the direction of this movement to the left or right is carried out according to a criterion to be determined.

In this work, we have defined the movements of the initial kernel points in an equal manner over the entire universe of discourse. As a particular case, all kernel points of a membership function of the two inputs (F_1,F_2) and (F_3,F_4) respectively move by the same distance "f" and in the same direction (left or right) and the extreme kernel points (left and right) are kept fixed. The function that defines the displacement "f" is defined as follows:

$$f(z) = \begin{cases} d = random[-150, +150] & \text{The variation of the displacement} \\ f^1_{(i+1)}(z) = f^1_i(z) + d & \text{The displacement of the kernel point (S1, A1)} \\ f^2_{(i+1)}(z) = f^2_i(z) + d & \text{The displacement of the kernel point (S2, A2)} \\ f^3_{(i+1)}(z) = f^3_i(z) + d & \text{The displacement of the kernel point (S3, A3)} \\ f^1_{(i+1)}(z) < 2600 & \text{to ensure } f^{1,2,3}_{(i+1)}(z) \in [100,\ 2600]{=}\text{D (the universe)} \\ f^3_{(i+1)}(z) > 100 & \text{to ensure } f^{1,2,3}_{(i+1)}(z) \in [100,\ 2600]{=}\text{D (the universe)} \end{cases} \tag{3}$$

The choice to keep the displacement "d" is unique for the displacement of the three kernel points in order to maintain the shape of the triangular fuzzy sets, during all the time, (study of a particular case of time-varying fuzzy sets). The value of this displacement "d" is bounded by the predefined range [-150, +150], this range is chosen on the basis that it is small at the ranges of linguistic values approximately [20% - 30%]. For the criterion of the direction of displacement of the kernel points is simply defined as follows: If this distance "d" is positive the displacement is to the right and otherwise the displacement is to the left. So the fuzzy set used in real time looks like a spring. See the following figure:

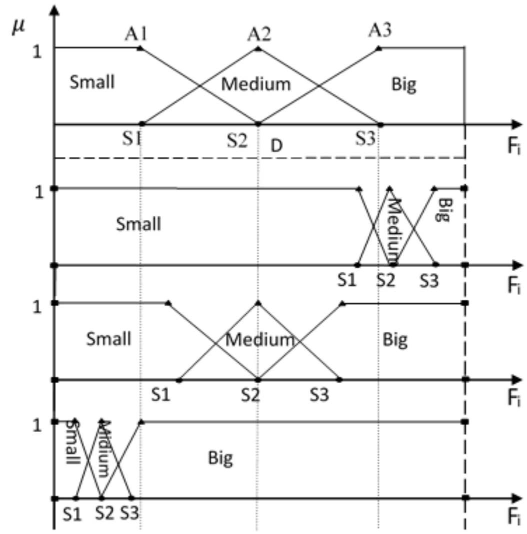

Figure 7: The time-varying fuzzy set in real time.

For this section we propose, at each end of the operation's use, that the support points and the corner points for each fuzzy set of fuzzy system inputs move to the right or to the left side by a distance defined randomly (Random [-150, +150]) according to the equation (3). We used this approach time-varying fuzzy sets (VFS) to ensure that the outputs of the fuzzy system is not the same if the same inputs occur again.

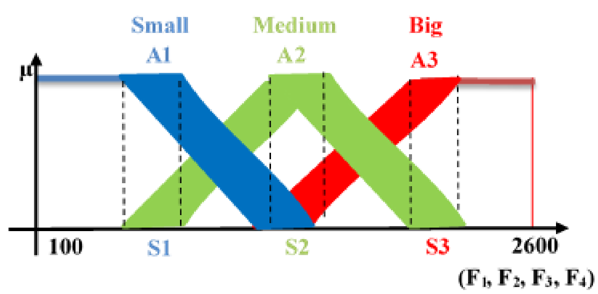

Figure 8: Time-varying fuzzy sets interval .

3.3 Generation of the coordinates (I, J) block

In this block, starting from the values of the fuzzy systems resulting outputs forces (F_I, F_J respectively) figure 2, we use the modulo operator algorithm [3, 11, 12, 18] to generate an integer (I and J respectively) between 0 and 3 (modulo 4), or $(I, J) \in [0, 1, 2, 3]^2$, when the display matrix size (M_D) is (I, J) = 4X4. The two found values of the coordinates (I , J) represents the first position of the new display matrix ($M_{D(i+1)}$) of the virtual keyboard, or

$$M_{D(i+1)}(0, 0) = M_{D(i)}(I, J). \tag{4}$$

3.4 Display matrix development block

The function of this block is to construct the new display matrix ($M_{D(i+1)}$) or (M_{DNew}) from the first randomly generated coordinates (I, J). This function is summarized in the following algorithm 3 and is illustrated in the figure 9 :

Algorithm 3 Procedure : Display matrix development

Require: m=0; n=0; Max= 4x4=16; k=(I, J); P=(I, J);(* parameters initialization*)
Ensure: M_{DNew} (m, n)= M_{DOld} (I, J); (* or M_{DNew}(l, m)= M_{DOld}(k)*)
  Label : Label11
  if $k + 2 \leq Max$ **then**
    k=k+2; m=m+1; n=n+1; M_{DNew}(m, n)= $M_{DOld}(k)$; goto Label11;
  else
    k=p; (* reload the initial (I, J)*)
    Label : Label12 :
    if $k + 1 \leq Max$ **then**
      k=k+1; m=m+1; n=n+1; M_{DNew}(m, n)= M_{DOld} (k); goto Label12;
    else
      k=p; (* reload the initial (I, J)*)
      Label : Label13
      if $k - 1 \geq 0$ **then**
        k=k-1; m=m+1; n=n+1; M_{DNew}(m, n)= M_{DOld} (k); goto Label13;
      end if;
    end if;
  end if; $M_{DOld} = M_{DNew}$; (* save the last display matrix*)
  end;

The advantages of this proposed display matrix development, the first point is to generate a random matrix display. As second point, in a particular case, is to guarantee the change of all the rest of positions of the new display matrix ; when the generated coordinates (I, J) = (0, 0). This is implicate that the first position of the new display matrix is not changed.

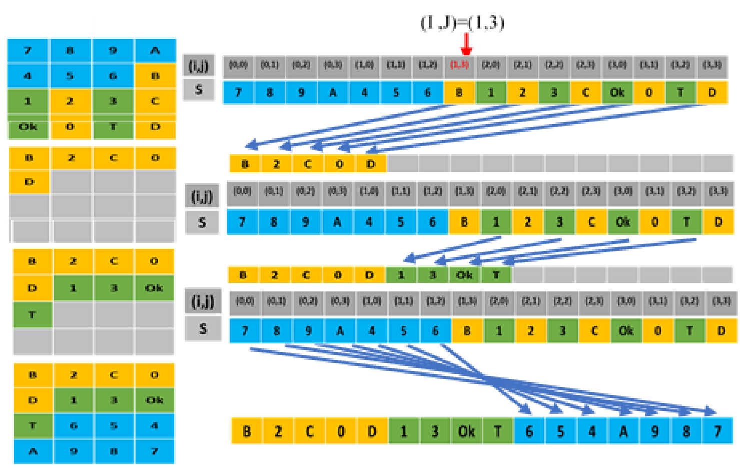

Figure 9: Display matrix development scheme (as example : (I, J) = (1, 3)) .

3.5 Display of the new matrix

This block is dedicated to displaying the new random matrix "MD_{New}" of the virtual keyboard, by using the corresponding library of the used touch screen device [1, 2, 5, 29].

4 Realization of a random display system of a virtual keyboard

To realize the proposed design, we used an ESP8266 microcontroller [5] and an ILI9341 touchscreen [1, 2, 29]. The ESP8266 is a system on a chip (SOC), Wi-Fi microchip for Internet of Things (IoT) applications [4] produced by expressive systems, characterized by its low cost (5V0, 0.5A), small size and adaptability with embedded devices. The

ESP8266 microcontroller can be easily programmed using your Arduino IDE (C/C++). The ILI9341 touchscreen is characterized by size 2.8", ILI9341 TFT LCD Screen Display Touch Panel, SPI Serial, 240*320, 5V/3.3V, for Arduino and Raspberry [29].

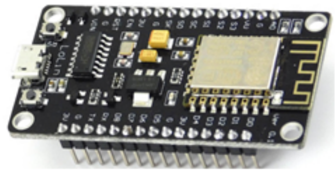

Figure 10: Hardware used for the realization (ESP8266 Microcontroller) .

Figure 11: Hardware used for the realization (ILI9341 Touchscreen) .

The realization of the proposed design is given by these figures

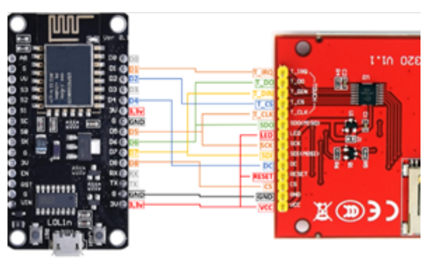

Figure 12: Cable schematics .

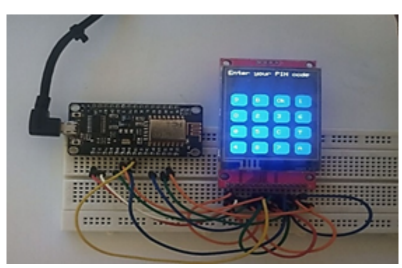

Figure 13: The prototype realized .

5 Realization results

The following images (figures) represent the display matrices trained after several uses (from use N° 0001 to use N° 1000 successively) knowing that the first display matrix is initialized to the standard one. In the case of the interruption of the current, the first matrix is initialized at the standard one. In this figure 10, the real photos of the results found, we can see that if the code is correct the display matrix of the virtual keyboard changes after the end of the operation "Continue the operation tasks" and the "removal of the monetary card". If the code is incorrect, the virtual keyboard display matrix systematically changes, regardless of the choice of Retry the operation (T) for three possible offers at most or Cancel (C) completely the operation with "removal of the card". The display matrix of 4X4 size, which including ten (10) numbers (0-9) and three (3) characters : "Ok", "T" and "C" to validate, Try again or Cancel procedures respectively and the characters "A", "B" and "D" are not used, is for more security than 4X3 size.

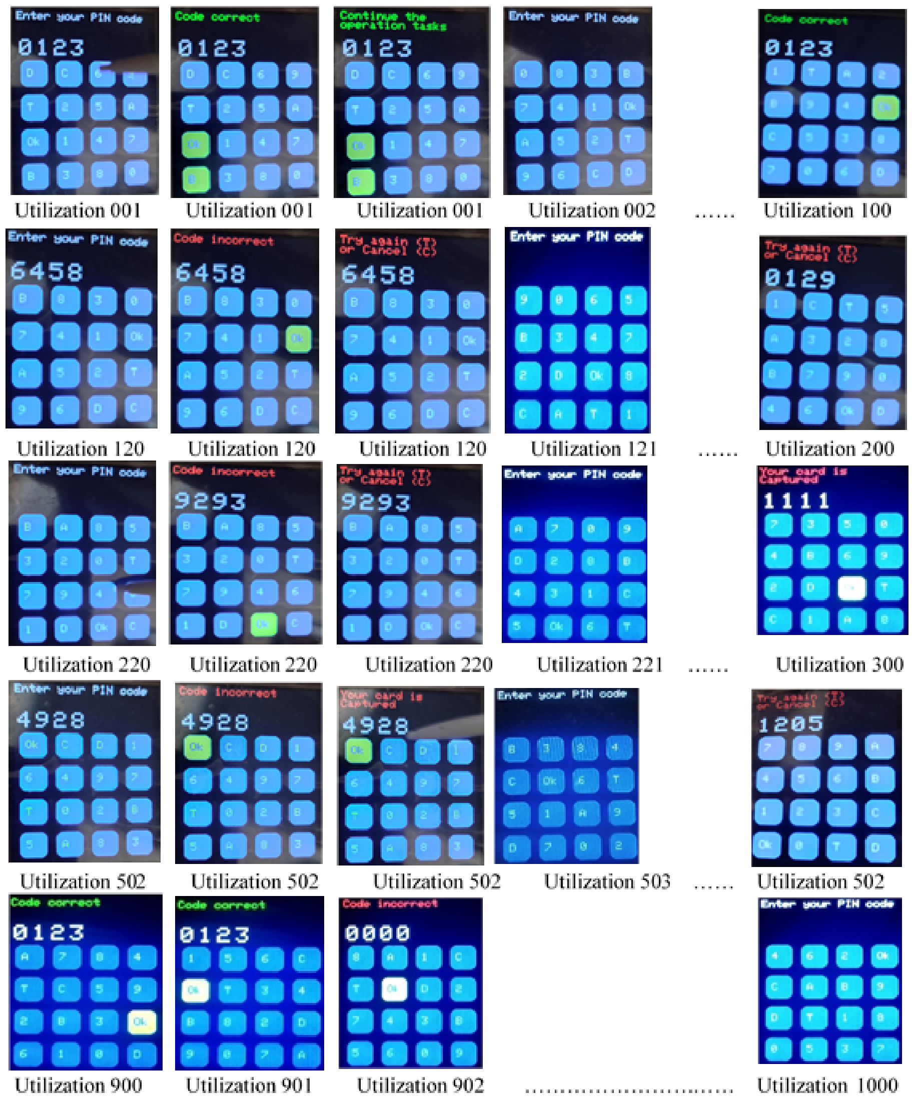

Figure 14: The 1000 successive operations of the virtual keyboard display matrices .

6 Conclusion

With the emergence of a variety of Internet services, invoices for these services are increasingly issued in electronic form, including electronic money cards (postal or bank) are the most used means. Therefore, the security of these payment methods has become a necessity. In this work, we suggested the creation of a new virtual keyboard with random display, to secure the personal information of the users during its use. The proposed implementation essentially exploits the fuzzy logic system based on time-varying fuzzy sets to randomly display a virtual keyboard matrix. Fuzzy systems use virtual keyboard keypress forces (F_1, F_2) (F_3, F_4) exerted by the user as random inputs to the fuzzy systems. The outputs of the fuzzy systems (F_I, F_J) are generated randomly using the time-varying fuzzy system. The coordinates (I, J) of the display matrix are also generated randomly by using a classical algorithm (operator modulo4) and finally the display matrix is randomly too developed. The concept of this contribution is that we take advantage of the current use or operation to generate the display matrix of the next use in a random way and in real time. The proposed design relies on combinations of sub-algorithms starting with the fuzzy system, which use the force of key presses as inputs, which makes its detection difficult. The experimental results found show the effectiveness of the proposed design for displaying a random virtual keyboard, more than 1000 utilizations, all the generated matrices are completely different (not doubled). In addition, in our approach, the initial values are not important, even if they are captured by hackers, because these four digits to be entered have their positions seen or detected by hackers. They represent, in the context of the algorithm, forces generated by the touchscreen, where these forces depend on the mood and personality of the user. It is impossible for the same user to reproduce the same forces! Finally, this realization can be easily integrate into any ATM system such as postal or banking, or into another one for different utilizations.

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