Qubit State Representation Using a Tangible User Interface

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I. Introduction

For this assignment, I chose to combine my area of research for my master's degree into the creation of a creativity support tool (CST) with a tangible user interface (TUI). I made this decision because I wanted to find an intersection between this course and my work. My research area is Quantum Software Engineering, and this CST uses some core concepts from this field. To understand this tool, we must first understand the basics of quantum computing.

In a classical computer, the one you are using to read this document, information is stored in bits. A bit can only be in one of two states: zero or one. On the other hand, quantum computers store information using qubits, which can be in the state zero, one, or a superposition of zero and one. When we measure a qubit, however, its state collapses to one or zero, each with some probability. This behavior allows for greater computational power and quantum computers have been shown to achieve better performance than classical computers in certain problems [1].

II. Purpose of the tool

I believe children will be learning about quantum computing in the future, since it will likely become part of our lives and therefore an important concept for kids to grasp. The purpose of this tool is to help children learn about how a qubit works. The CST is framed in the educational environment and is designed for children from 8 to 12 years old. By illustrating the behavior of a qubit through a TUI, children will be able to grasp concepts that are not intuitive, and that would otherwise be harder to understand using a computer. A TUI gives children a way to interact with technology that feels natural and intuitive to them [2]. In this case, the focus of the CST is to better illustrate the state of a qubit using LEDs as an output mechanism. It supports the creative learning process of children in the Mini-C category, allowing them to become familiar with quantum computing and eventually put these concepts into practice.

III. Motivation

Learning about quantum computing is a challenge for many people, since the concepts involved in this field are not intuitive. The learning process usually involves a lot of math, accompanied by some visualizations to illustrate the behavior of qubits. However, these visualizations are usually accomplished using a computer, a device that is not intuitive for children between the ages of 6 and 12 years old [2]. Moreover, in the case of quantum computing learning for children, there are a lot of concepts that can be simplified and abstracted. For example, given a qubit in a superposition state, the probability that the qubit will collapse to the 0 state or the 1 state can be shown by two LEDs blinking at different intervals, where faster means a higher chance that that will be the output when measuring a qubit. I believe this alternative output is a more intuitive way of visualizing the state of the qubit for children.

IV. The System

A. The tangible user interface

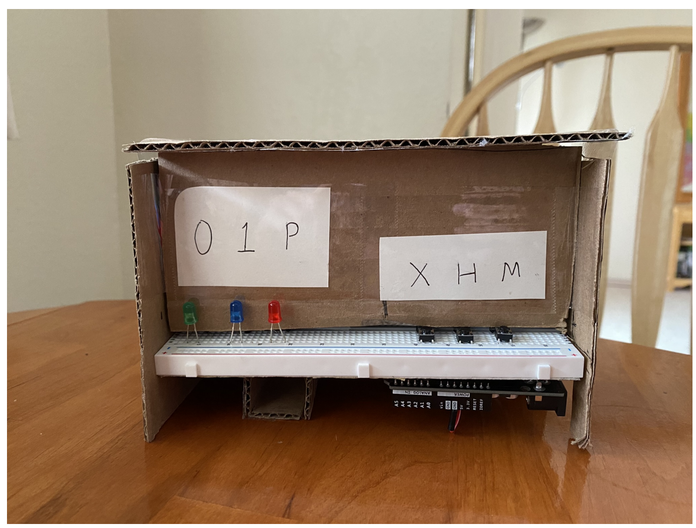

Fig. 1. The CST

The goal of this CST is to be very minimal. It is meant to be used in the classroom, supervised by a teacher. It is not meant to be moved around, but rather it can be seen as a stationary tool that children can interact with. Having this in mind, the tool is designed to encompass all the electronics and only show the output and input mechanisms. It can be thought of as a mini quantum computer with one qubit (although in reality there are no real qubits implemented since this would require a tremendously big and expensive infrastructure) that performs three basic operations and shows the current state of the qubit. The three basic operations are the Hadamard Gate, the NOT Gate and a measurement of the qubit. Each of these has a dedicated button that will trigger the execution of the operation.

A thorough explanation of these three quantum gates is outside the scope of this document, but I will try my best to describe their behavior in simple terms. As said before, the qubit can be in many different states. It could be in the state zero, the state one, or an infinite number of superpositions between zero and one. The way to change the state of a qubit is by applying quantum gates, and the three gates that are available in this CST illustrate some basic but important concepts. The Hadamard Gate is the one used to put the qubit in an equal superposition of zero and one. After applying this gate and measuring, the qubit has 50% chance of being a zero and 50% chance of being a one. The NOT Gate simply flips the state from zero to one and vice versa. Lastly, the measurement operation collapses the qubit state.

The current state of the qubit is displayed at all times by blinking three LEDs. Two of the LEDs will blink at a given interval to illustrate the probability of the qubit being measured as either one or zero. As seen in the picture, the green LED outputs the probability of zero and the blue LED the probability of one. The red LED shows the phase of the qubit. Let me explain the concept of a phase: when an operation is applied to a qubit, a phase of negative one might arise from multiplying the satevector and the matrix representing the linear operator. The purpose of this LED is to show whether this phase currently exists in the qubit state.

The materials used to build this tool were: pieces of cardboard, tape, the ELEGOO board, a breadboard, and the other electronics (LEDs, cables, resistors and buttons). The skeleton of the tool can be seen figures 2 and 3. It was built by taping pieces of cardboard together. The circuit is captured in figure 4.

Fig. 2. View 1 of the skeleton

Fig. 3. View 2 of the skeleton

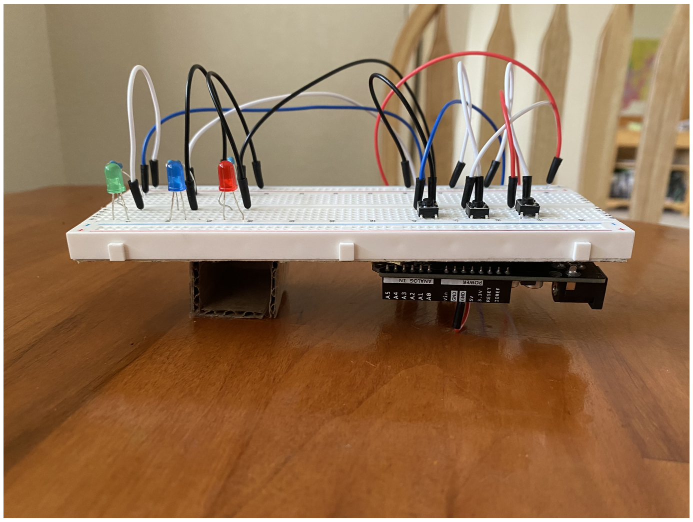

Fig. 4. ELEGOO board with circuit

B. The code

The program executing in the ELEGOO board simulates a qubit by storing its current state. Each of the operations (Hadamard, NOT and measurement) have been implemented realistically and simulate the real behavior of a qubit. For a more detailed explanation, please refer to the code available on this github repository or go to the next url: https://github.com/jmossorio99/CST-qubit.

V. FUTURE WORK

This first implementation of the CST could be improved in some ways. Here are some ideas that I would like to implement in the future:

- Incorporate extra quantum gates to be able to put the qubit in different superpositions
- Increase the number of qubits to two in order to showcase the concept of entanglement

- Change the material used for the skeleton of the tool to make it look more aesthetically pleasing

REFERENCES

[1] J. Preskill, "Quantum computing in the nisq era and beyond," *Quantum*, vol. 2, p. 79, 2018.

[2] G. J. Smets, P. J. Stappers, K. Overbeeke, and C. van der Mast, "Designing in virtual reality: implementing perception-action coupling with affordances," in *Virtual Reality Software And Technology*. World Scientific, 1994, pp. 97–110.