TangiNet: A Tangible User Interface System for Teaching the Properties of Network Cables

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***Abstract*— Within many computer science related courses, networking is often included as a core module due to industry needs. An important topic within networking involves teaching students the properties of network cables and many students however find it challenging to learn networking-related topics thus reducing interest and motivation for learning. Through the use of Tangible User Interfaces (TUI), such challenges could be potentially addressed although limited work has been undertaken to create systems that teach networking related topics. In order to address this gap, this paper investigates the application of tangible user interface for teaching the properties of network cables through a proposed system called TangiNet. The proposed system was evaluated to assess four key aspects, namely, learnability, interaction, tangibility and enjoyment. For all the constructs investigated, positive overall results were obtained thus implying that such tool could be adopted in networking related courses for the addressed concepts.**

***Keywords*— *TangiNet, Tangible User Interface, Network cables, Computer Science, Networking, Teaching, Education*.**

I. Introduction

With the widespread use of networking within the business world, it has become imperative to prepare graduates with the required skills and knowledge [1]. Consequently, computer networks is often included as a core module in many computer science courses [2]. Among the networking related topics, teaching the properties of network cables such as coaxial, twisted pair and fibre optic is essential to properly setup and maintain networking infrastructure within organisations. However, networking concepts are currently being taught using mostly traditional methods of teaching [1] and the issue with conventional lectures is one way communication, thereby reducing interaction with students [3]. As such, many students thus find it challenging to understand both the theoretical and technical aspects of networking thus reducing interest and motivation for learning this subject [4]. In order to address this issue, it is believed that students would learn networking concepts more effectively from courses that provide improved involvement in practical activities [2]. Likewise, different studies showed that having students to actively participate in the learning process improves retention of knowledge as compared to sitting and receiving information without performing any physical actions [5, 6].

One interaction technology that could potentially address the issues discussed above towards improving interaction and understanding of networking concepts is the use of Tangible User Interfaces (TUIs) [7]. TUI is a new form of interface that has broken the barriers of the traditional Graphical User Interface (GUI) by allowing users to interact with the digital world through the manipulation of real-life physical objects rather than using the mouse and keyboard as input devices [8]. During the previous years, TUI has gradually gained popularity especially in the research and educational fields [9] and has shown to encourage cognitive learning through manipulation of physical objects [10]. It was previously shown that the use of TUI allows learners to easily grasp concepts by actively participating and engaging in the learning process [11].

Even though TUI could potentially address issues related to teaching networking, limited research has been made involving its application to teach this aspect. As such, with limited work undertaken in this area, this paper investigates the use of tangible user interface for teaching the properties of network cables. This paper is intended to be beneficial to higher education institutions teaching properties of networking cables within computer networking related courses towards improving interaction and student engagement.

This paper is structured as follows: In the next section, a review on different works related to TUI is given. The implementation of the TUI-based system for teaching properties of networking cables is then discussed in section III. In section IV, the evaluation method used to evaluate the proposed tool is described before presenting the findings of the evaluation in section V. Finally, the research is concluded in section VI.

II. Related Works

As related works, different studies have utilized TUI for teaching and learning. The ‘Towards Utopia’ project aimed at teaching concepts related to land use planning and sustainable development to children aged between seven and ten [12]. In the same study, it was found that the proposed prototype increased children’s learning score by 20%. Likewise, the ‘Illuminating Light’ project was used to simulate the propagation of laser lights on different surfaces [13]. After carrying out a user testing process, the authors concluded that the prototype was effective but cannot entirely address all types of holographic layouts due to the projection-based system used. Moreover, through the ‘Tangible Tiles’, different interaction and collaboration techniques were investigated by making use of optically tracked transparent plexiglass tiles [14]. Although the study showed that the proposed prototype was able to address basic interactions, some conceptual issues regarding the learnability and intuitiveness of the system was also discovered. Besides, several frameworks for TUI have been proposed over the years to guide designers and developers to create TUI-based systems [9]. Koleva et al’s framework is one such framework which aimed at investigating on the degree of coherence between physical and digital objects [15]. The proposed framework described the links between physical and digital objects by using a set of underlying properties.

In relation to computer networking, a previous study developed a TUI-based Internet Protocol network design workbench for network simulation [16]. Even though the authors believed that the proposed solution makes the exercise of network design more accessible to students having limited network design skills, no evaluation was conducted to evaluate this statement. Similarly, another study proposed a TUI system for teaching network topologies and protocols [17]. Although findings of the study were insightful where the TUI system was found to improve learning by approximately 25% as compared to traditional techniques, the focus of the work was not on teaching properties of networking cables.

III. PROPOSED PROTOTYPE

In order to achieve the purpose of this paper, a TUI based system called TangiNet was designed and implemented with the aim to teach properties of network cables, including twisted pairs, coaxial cables and fibre optics. The prototype and tangible interaction involved are described as follows:

A. *Prototype Description*

TangiNet is made up of two components, namely, a learning component and a quiz component. The learning component employs the concept of exploratory learning where the user learns by performing a set of activities and then observing the results [18]. A similar approach was used in the Illuminating light project [13]. The learning component consists of three screens each for learning about the properties of a particular type of network cable, notably, twisted pairs, coaxial cables and fibre optic cables. When using TangiNet, the user has to follow a set of instructions given in form of text and voice in order to create a wired connection between two devices, for example, creating a twisted-pair connection between a laptop and a router. The user first has to place the miniature device objects such as the laptop and router objects in specific areas on the screen. The user then needs to place the connector object in a box found beneath the first device and then drag the same connector object to a box found beneath the second device object simulating a connection between the two devices. After placing all the required objects in the correct locations, a link between the two device objects is created as depicted in Fig. 1. The image of a cable is displayed between the two devices along with an animation showing the transmission of data through the cable from one device to the other. Different animations were used for illustrating the data transmission of each type of network cable. Information about the cable structure, transmission speed and maximum cable length are also displayed. Further information about the particular type of network cable is provided to the user in form of voice.

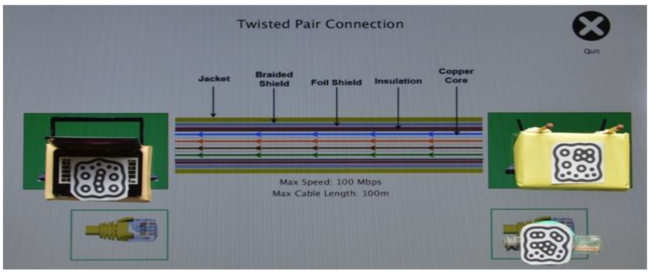

Fig. 1. Learning about Twisted-pairs

The second component of TangiNet is the quiz feature. Its purpose is to test the knowledge that the user has gained from the learning component. It consists of three multiple choice questions that require the user to place the alphabet (A, B, C, D) objects to select an answer and place the question mark (?) object to verify his answer. The questions are related to the characteristics of the different network cables taught in the first component. The quiz also consists of two practical questions where the user needs to carry out tasks such as arranging network connectors in a specific order and labelling the structure of a cable as shown in Fig. 2. These were included to make the system more interactive and fun.

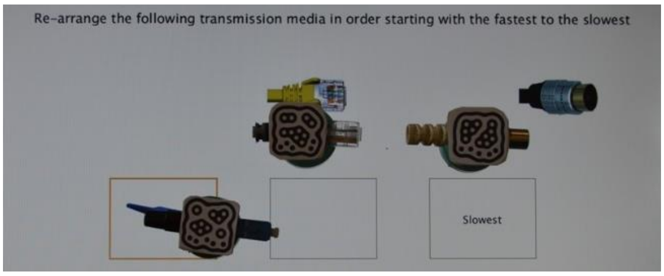

Fig. 2. Screenshot of Quiz feature

B. *Tangible Interaction*

TangiNet involves three major types of user interactions. The first type of interaction involves placing specific physical objects on the screen, e.g., placing a specific alphabet object on the screen to select an answer for the multiple choice questions. The second type of interaction involves moving and positioning physical objects to specific locations on the screen, e.g., moving the laptop object in a predefined box. The third type of interaction involves rotating an object to a specific angle, e.g., rotating the Rotary Switch object to either switch to the single-mode or multi-mode of the fibre optic cable. In order to correctly employ the concept of tangible interaction, the framework proposed by Koleva et al [15] was implemented for this project. Particular attention was given to creating the tangible objects and making them as coherent as possible to their digital representations. A unique fiducial marker was placed on each physical object for them to be identified by the ReacTIVision. The objects created are depicted in Fig. 3 and were categorised in three groups, namely:

- *Miniature Devices and Connectors*

  According to the coherence continuum of Koleva et al [15], these objects possess quite a strong level of coherence and are closely related to the digital objects represented. The objects in this category include the laptop, TV screen, router, antenna as well as the connector objects (coaxial cable, twisted pair and fibre optic). The user usually manipulates these objects by placing them on the screen and moving them to specific locations. The type of transformation is literal as the movement of the physical object results in the same exact movement of the digital image on the screen.

- *Rotary Switch*

  The Rotary Switch object is a special object that is used specifically on the fibre optic cable screen. The user needs to manipulate the object by rotating it to a specific angle in order to either switch to the single or multi-mode of fibre optic transmission.

- *Alphabets, Numbers and Symbols*

The objects in this category are usually manipulated by simply being placed on the screen. These are not required to be moved to specific locations and rotated to specific angles. The alphabet objects (A, B, C and D) are used to select the multiple choice answers and the number objects (1-5) are used to navigate to different screens throughout the system. The zero object (0) is specifically used to retry a quiz question. The symbol objects include the question mark (?) and cross (X) objects. The question mark object is used to check answers during the quiz and the cross object is used to quit a screen and to return to the main menu.

Fig. 3. Tangible Objects

C. Prototype Implementation

For implementing the TUI system, the software architecture used is composed of three elements, namely a TUIO tracking application, the TUIO protocol and a TUIO client application. A similar architecture was used in the Towards Utopia project [12]. ReacTIVision has been used as the TUIO tracking application to track the movements of tangible objects marked with fiducials using images obtained from the webcam. The TUIO client application is the TangiNet application that has been developed using Processing. All screens of the system were created as Processing sketches. Besides the TUIO library, the Minim library was also used to add sound and voice to the application.

As for hardware setup, an adapted version of the setup used in Tangible Tiles [14] was used. The layout is depicted in Fig. 4 and involved a monitor placed horizontally on a table for display onto which the user would manipulate the physical objects. A webcam was mounted on a tripod facing downward in order to capture the movements of the tangible objects placed on the screen.

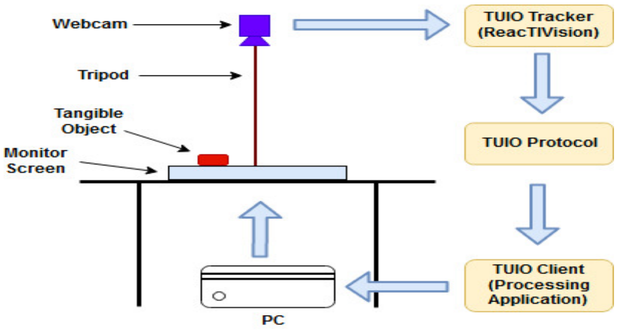

Fig. 4. Hardware setup and software architecture used for TangiNet

IV. Evaluation Method

In order to evaluate TangiNet, two evaluation methods were used. The first method was observation where participants were observed by the evaluator while interacting with the system. This method was chosen to help identifying points of confusion and hesitation and is common for evaluating TUI-based systems [19]. The second method involves application of a TUI-evaluation framework previously used in the Tangible Tiles project [14] due to the similarity in hardware setup and configurations. The framework assesses TUI systems based on four constructs, notably:

- *Learnability*

According to Nielsen's usability model, learnability refers to how easy it is for users to learn to use a system and perform basic tasks on the first encounter with it [20]. Assessing the learnability aspect of the system proposed in this paper was essential as TUI is a new type of interface that many students have probably never encountered before. Therefore it is important to determine if the system has been designed properly to allow new users to easily learn to use it and perform the required tasks [21].

- *Interaction*

Interaction refers to the involvement of a user with a particular system and how he/she communicates with it and controls it [22]. Contrary to GUI-based systems, the prototype proposed in this paper made use of physical objects having different forms and sizes which is quite unusual for students and might cause challenges. The system also required users to perform various actions such as rotational movements with those objects. Therefore it was essential to assess the interaction aspects of the system to determine whether it was easy to handle the objects and accomplish the required tasks.

- *Tangibility*

Tangibility refers to the capability of being precisely identified by the mind and sense of touch [23]. Tangibility was assessed in order to determine if users are able to easily recognise the physical objects and relate them to real life.

- *Enjoyment*

Studies have shown that enjoyment has a positive effect on learning [24, 25]. It was therefore important to include this construct in the evaluation to determine if the system was engaging and fun enough to improve the learning process of the students.

A questionnaire was designed based on the above constructs, each containing different statements to be answered using a Linkert-5 scale. Using this scale, a score of 1 would mean that that the participant strongly disagrees with a statement whereas a score of 5 means that the participant strongly agrees. Within the questionnaire, a comment section was also included at the end of each construct to allow participants to express their opinions. The constructs along with the measured items used are given in Table I.

TABLE I. TUI Evaluation Framework

Construct	Measured Item
Learnability	L1 - It was easy to learn how to use the system. L2 - It was easy to know what actions

	needs to be performed. L3 - It was easy to learn about the properties of network cables.
Interaction	I1 - It was easy to grab the physical objects. I2 - It was easy to move the objects. I3 - It was easy to rotate the objects.
Tangibility	T1 - I could handle the physical objects like real-life objects. T2 - I could work in a natural way. T3 - It was easy to recognize the physical objects. T4 - I found the physical objects closely related to their digital representations.
Enjoyment	E1 - The system was engaging to use. E2 - It was fun to use the system.

Following preparation of the questionnaire, an experimental study was conducted in the labs of Middlesex University Mauritius involving 23 students studying Information Technology (IT) related courses. This target audience was selected as computer networking is part of their curricula and students were recruited directly in the labs after classes. The number of participants selected also exceed the count needed using the adopted evaluation framework [14].

As procedures of the experiment, a brief on the research was given to each participant to explain the purpose of the study and process involved. Informed consent was also obtained from each participant involved in the study. With every participant, the initial setup illustrated in Fig. 4 was initiated to ensure the objects are off screen and the application is restarted. The participant then had to perform a series of tasks given while using TangiNet and this involved using the learning and quiz components. As the participant was performing the tasks, observations on interaction and challenges faced were recorded. After exploring the system, the participants were given the questionnaire to fill in. While collecting the filled-in questionnaire, the research team ensured that all needed sections were correctly filled in so as to ensure reliability of the collected data. Finally, the questionnaires were statistically analysed on SPSS.

V. RESULTS AND DISCUSSIONS

Using the previously defined evaluation approach, the average scores obtained for the different constructs were calculated and compiled. The results obtained for each category are discussed as follows.

A. Learnability

Among the items investigated, the highest mean score of 4.5 was obtained for L3 as most participants found that it was easy to learn about the properties of network cables. Participants also found the use of voice and animations to complement the learning process. On the other hand, relatively lower scores of 3.7 and 3.3 were obtained for questions L1 and L2 respectively. This was mainly due to the fact that two participants were confused while moving the connector objects inside the boxes on the learning component screens. A group of participants did not know whether to put a different connector object inside the second box or move the same one. The low scores were also because of the difficulties some participants faced while navigating through the quiz questions. As such, further instructions are needed to make it more intuitive for end users to learn about different objects to be used for navigation. Overall, a mean score of 3.8 was obtained for this category and results are given in Table II.

TABLE II. MEAN SCORES FOR LEARNABILITY

	Item	Mean Score
L1	It was easy to learn how to use the system	3.7
L2	It was easy to know what actions needs to be performed	3.3
L3	It was easy to learn about the properties of network cables	4.5
	Overall Mean Score	**3.8**

B. Interaction

As interaction relates to the manipulation of physical objects and user interactions, participants found it easy to grab, move or rotate the physical objects since a score above 3 was obtained for each item under this construct. The highest scores were obtained for I1 and I2 respectively, where due to the appropriateness of the size of the objects, participants found all of them easy to grab and move. However, a lower score was obtained for I3 where some participants had difficulties in rotating the rotary switch object. Moreover, at times, participants covered the fiducials with their hands when rotating objects, thus preventing the webcam from effectively detecting a rotation. Overall, a mean score of 4.5 was obtained for interaction and results are given in Table III.

TABLE III. MEAN SCORES FOR INTERACTION

	Item	Mean Score
I1	It was easy to grab the physical objects	4.9
I2	It was easy to move the objects	4.8
I3	It was easy to rotate the objects	3.9
	Overall Mean Score	**4.5**

C. Tangibility

This category consisted of 4 items that addressed the tangible aspects of the system and results are given in Table IV with a mean score of 4.5 obtained. Among these items, the highest scores were obtained for T3 and T4 respectively where most participants found the physical objects closely related to their digital representations and that it was easy to recognize the physical objects. On the other hand, a relatively lower score was obtained for T2 as a few participants took some time to recognise objects including the antenna and router. Three participants complained about having to use too many objects for answering the multiple choice questions in the quiz component. In TangiNet, participants had to use the Alphabet object for selecting an answer, use the Question mark object for verifying the answer and use the Number Zero object to retry the question in case an incorrect answer was provided. One participant suggested that the answers could automatically be verified once the alphabet object is placed on the screen and the question to automatically reset if a wrong answer is given, without the use of additional objects. Better physical representations of these objects could be used in the future to avoid confusion.

TABLE IV. MEAN SCORES FOR TANGIBILITY

	Item	Mean Score
T1	I could handle the physical objects like real-life objects	4.5
T2	I could work in a natural way	4.2
T3	It was easy to recognize the physical objects	4.6
T4	I found the physical objects closely related to their digital representations	4.6
	Overall Mean Score	**4.5**

D. *Enjoyment*

This category consisted of only two questions asking the participants to rank the system based on how engaging and fun it was to use. Table V shows the mean scores obtained after evaluation and overall, a mean score of 4.7 was obtained. The majority of the participants found that the system engaging and fun to use and for all participants it was a first experience with a tangible user interface which could also influence the results obtained. Participants mentioned that TangiNet taught networking concepts in an innovative way. Whilst some participants found the physical objects intriguing, others found the use of animations and voice interesting for learning. One participant suggested that in addition to animations and voice, short video explanations could have been provided to enhance learning. Another participant suggested that using a story-line could make the system look more like a game thus making it more engaging and fun to use for students.

TABLE V. MEAN SCORES FOR ENJOYMENT

	Item	Mean Score
E1	The system was engaging to use.	4.7
E2	It was fun to use the system.	4.7
	Overall Mean Score	**4.7**

E. *Discussions*

Among the four constructs assessed, the lowest mean score was obtained for learnability where among the statements investigated, some participants found it challenging to understand about the actions that need to be performed. This could also be attributed to the fact that since the participants were familiar to GUI environments, changing interaction technology implied some further time and effort was needed to learn how to manipulate the physical objects in order to interact with the system. On the other hand, enjoyment was found to score the highest as the participants found TangiNet engaging and fun to use. The chart comparing the results gathered for the four constructs is given in Fig. 5. Overall, a positive mean score of 4.4 was obtained showing that the tool could be potentially integrated in networking related courses for teaching students the properties of networking cables. However, implementation within labs also have its challenges according to the participants. Firstly, since many miniature objects are used within TangiNet, losing any of these small object would affect utilization of the tool. In addition, inventory tracking of such physical objects also becomes an issue, especially if various such TUI-based solutions are used for teaching.

However, the study was also limited by in different ways. First of all, the participants used the TUI environment for the first time and this could be why enjoyment was found as the most positive construct from the experiment. The same experiment could have been conducted with users who have experience with TUI environments to assess any effects on results received. Furthermore, although the study relate to teaching students the properties of networking cables, assessing whether the TUI approach used effectively helped in learning could have been helpful, although this was beyond the scope of investigation for this paper.

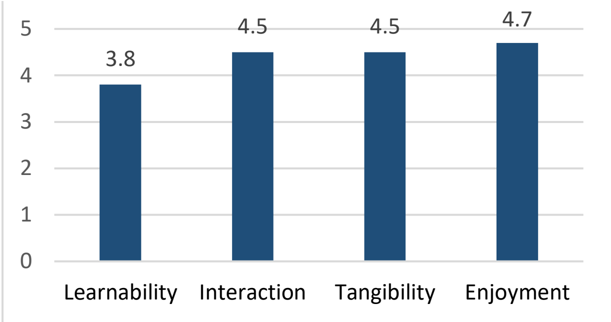

Fig. 5. Comparison amongst studied constructs

F. *Recomendations*

Several issues and points of confusion were identified during evaluation. As such in this section recommendations for improving certain aspects of TangiNet are discussed. These recommendations could also be taken on board by researchers and developers of TUI to improve their solutions right from the beginning:

- *Clearer instructions and digital feedback*

Issues regarding moving and placing connector objects arose when users had to place the same connector object in the second box to complete the network connection. Many users first thought that another connector object should be placed in the second box. To solve this issue, better instructions in form of voice could be provided. Clearer instructions in form of text such as "*Now drag the fibre optic connector to the second box*" could also be used. Additionally, validations could be used in the connector boxes to verify if an incorrect object has been placed and alert the user about it. This would help the user know if he/she has wrongly performed an action.

- *Improved navigation*

In order to navigate through the quiz questions, users had to make use of different objects in the form of numbers. For instance, in order to switch to question 3, the user had to place the Number 3 object and to move back to question 2, the Number 2 object was required. Making use of these different objects was sometimes confusing for the students. As such to reduce confusion, a single object representing an arrow could be used. Pointing the Arrow object to the right would move to the next question while placing the Arrow object in the opposite direction would move back to the previous question.

- *An optimum number of physical objects*

Different objects were required for answering quiz questions. For instance the Alphabets objects were used to select answers, the Question mark object was used to verify answers and the Zero object was used to reset questions in case wrong answers were given. It was found that a bigger number of objects made it challenging for the students to decide and select which one(s) to use. As a solution, an optimum number of physical objects could be considered when designing the solution. For instance, in the case of TangiNet, instead of making use of the Question mark object for verifying the answers, the answers could automatically be verified as soon as the user placed the Alphabet object on the screen. This would eliminate the use of unnecessary objects and thus improve the usability of the system.

- *The size of object matters*

Some students were found to have difficulties rotating the Rotary switch object. This was mainly because the object was too small and the students tend to cover the fiducial marker while holding the object which resulted in the object not being detected by ReacTIVision. A larger circular object could be used instead so that users can grab the object better on its sides without hiding the fiducial marker found on top of the object.

VI. CONCLUDING REMARKS

In this paper, the application of the tangible user interface was investigated for teaching the properties of network cables through a proposed system called TangiNet. This system was developed using Processing and ReacTIVision and contains two essential components namely, a learning and a quiz counterpart. In order to evaluate TangiNet, observation was used in addition to the application of a TUI evaluation framework to assess four key aspects, namely, learnability, interaction, tangibility and enjoyment. Evaluation was conducted involving 23 computer science students who had to use the system practically and provide feedback on the four constructs investigated through a questionnaire. Among the four constructs, enjoyment obtained the highest mean score as the tool was found to be fun and engaging to use by the participants. On the other hand, learnability received the least score particularly because participants took further time to learn how to interact with the objects in TangiNet. Overall, a positive mean score of 4.4 was obtained, although some conceptual and design related issues were revealed.

In terms of future works, more multiple choice and practical-based questions could be added to the quiz component to better test the knowledge of the user. Regarding evaluation, assessment could be conducted on whether TangiNet could effectively help in learning by conducting learning assessments (e.g. multiple-choice based tests) before and after using such tool. Further constructs could also be investigated, including user attitude while using the tool and collaboration. Finally, experiments to compare between GUI and TUI approaches could be conducted to assess and practically compare between interaction technologies.

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