System Complexity in Tangible Interaction

A case study in a safety critical context

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ABSTRACT
Our current understanding of the translation of subjective data into numbers in user interfaces has limited our capacity to perceive the intrinsic meaning associated with data and its source. Here, we envision a systemic tangible interaction framework that connects the user and data source by combining data physicalization and tangible manipulation. We illustrate the application of this framework through a case study on critical context of an anesthesia ventilator machine, where connection between data source, i.e patient, and user, i.e nurse, is vital. The framework enables the users to monitor, communicate, and manipulate the tangible data in real time. This thereby establishes a deeper connection between the data source and the user. Lastly, we analyze the challenges, limitations and future scope of the framework in this professional context through five prototypes - Fabric, Jellyfish, Projection, Organic, and Hybrid.

Author Keywords
Data physicalization; visualization; tangible user interfaces; shape-changing interfaces; physical visualization; medical industry.

INTRODUCTION
In all the recent developments in the tangible interactions, the research community has focused on the theoretical definition, concept exploration, education, and art installations. But a study of tangible user interfaces in a complex context has always been a challenge. In this project, we apply the tangible user interfaces in a professional context where safety is critical. By implementing TUIs in such a context, we learned more about challenges in the area of data communication, manipulation, usability, and system complexity. This helped us to open up possibilities for the research on the existing domain of tangible interfaces.

GUIs facilitate precise and diverse data communication and manipulation with pixels on screens, which can change the form, position, or properties, and color, size, and animation. However, it lacks in affordance and takes little advantage of hand-eye coordination. Everything looks and feels the same, and there is little differentiation in appearance and actions so the only way left to make a product communicate its functions is through icons and text labels, which requires reading and interpretation. We aim to design an artifact that communicates its purpose through its forms and the actions it requires. Therefore, a natural shift from the virtual world GUIs to physical world TUIs seems an inevitable choice. We take this opportunity to push the boundary of tangible interaction by placing the TUIs in a critical context. This study broadens our understanding of the systemic structure and the complex relationships between multiple intelligent actors and artifacts.

So far, the development of tangible interaction has paved the path towards the sensory richness and action-potential of physical objects as carriers of meaning in interaction [1]. Because they address all the senses, physical objects offer more room for expressiveness than screen-based elements. Data physicalization enables the user to interpret data with an artifact whose geometry or material properties encodes data and supports cognition, communication, and decision making [2]. We implement our insights from these studies in our design process.

In the first half of paper, we explore the ways to communicate and make data tangible through various prototypes and address the challenges associated with it. In the second half, we propose the tangible interaction framework that combines the data physicalization and tangible manipulation into one cohesive and dynamic system that connects data, data-source, and the user. We have developed this framework by embracing and understanding human-machine interaction in the critical context of the hospital. The following case studies present a series of explorations and insights derived from the ongoing design process.

CASE STUDY
We began our case study by looking at the interface for a ventilator machine used in the surgery, observing its interactions, functions and data communication. From here, we developed a series of prototypes that addressed the shortcomings and explored potential data

communication opportunities that were revealed from our initial study in the hospital context.

Figure 1: Currently used GUIs in the hospital

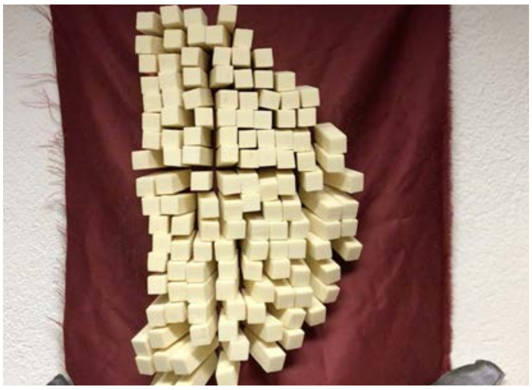


Figure 2: Fabric, a prototype simulating the respiration rate

Figure 3: The manual ventilation pump used in the hospital consists of a rubber valve to push air into the lungs

Interfaces used in the hospital

During the critical process of ventilation, the breathing data is translated into parameters on the graphical user interface (GUI) (Figure 1). Our field survey and qualitative interviews revealed that even though these parameters on a display contain essential information, they do not take advantage of the complete potential of computational technology. This leads to cognitive overload, steep learning curve and inefficient decision making. In most of the cases, the nurses perform numerous mental calculation using these parameters just as hints to understand the invisible phenomena of breathing.

When a complex invisible phenomenon like breathing is represented numerically and graphically through parameters like respiration rate, tidal volume, alveolar pressure (refer to glossary), it dilutes the rich human quality. Hence, moving forward with this idea, we designed artifacts to solve the limitations of GUI to facilitate a better translation of the breathing data with data physicality. We attempt to transfer emotionally rich input from the patient to the nurse while retaining the usability of interaction. This gives the user the opportunity for the users to directly control the data itself, by providing the nurse with the ability to manipulate precisely.

Data physicalization

We explored various ways to communicate the breathing data through data physicalization.

Fabric

In our first prototype called Fabric, we tried to mimic respiration rate of the internal lungs. In this case, the pixel data could be easily manifested in the form tangible objects [3].

Unlike GUIs, this representation of data in a physical form (Figure 2) gave us a novel alternative mode of communication.

Jellyfish

Today's manual ventilation (Figure 3) provides lots of hidden and qualitative information about the patient condition that can only be read by professional nurses. For example, the change in the muscle relaxation inside the lung during anesthesia is an information that can be felt faster through a tactile interface than a GUI.

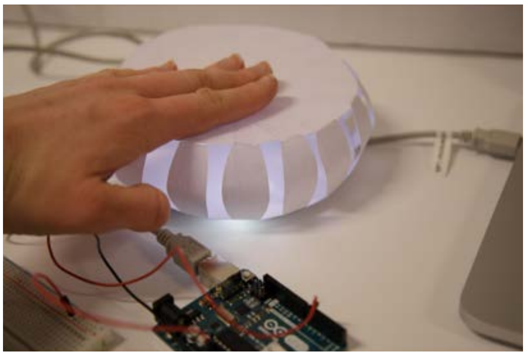


Figure 4: The jellyfish prototype simulates respiration rate through a haptic feedback.

Thus, we created an artifact where we tried to transfer that emotionally rich input from the patient lungs to the nurse by exploring a different type of physical variables e.g. resistance, pressure, stiffness to mimic the haptic feedback. The quality of feedback was further enhanced by a tactility (Figure 4).

Challenges

The primary challenges were the amount of patient data that was needed to be layered, timed, and communicated precisely to its user through this physical medium. The diversity of information and precision in the medical context posed a major challenge for us in physicalization because of lack of precision and data abstraction. We realized that not every type of data can be physicalized in a critical context as some data can be qualitative, quantitative or hybrid data.

Quantitative data

Some values such as partial pressure (Refer to glossary) of carbon dioxide and oxygen that can indicate the effectiveness of ventilation require accuracy to fractional parameters.

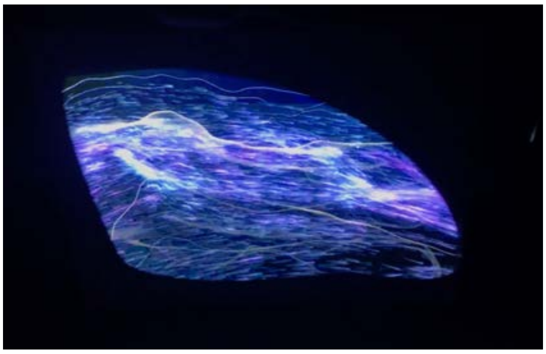


Figure 5: The projection prototype displaying the gas flow inside the lungs

We tried to communicate this accurate data through an animated sequence that we projected onto a surface. We simulated the particular functions of a patient's airway with a visualization of internal gas flow. We believe that this method of data communication can be abstracted to this degree since our aim is to provide the user with immediate quality of information. (Figure 5).

Qualitative data

Some value such as delivered pressures, volumes, breathing pattern, and gas flow inside the lungs are more visual and subjective and can be communicated in more abstracted modalities.

Hybrid data

Some data require multiple parameters in terms of quality and quantity. For example, a condition called partial collapse of lungs, is hard to detect as it requires several GUI parameters to guess. So we designed the *Organic* prototype (Figure 6) to physically materialize the lung collapse which might not have been possible with numerical parameters.

Figure 6: The organic prototype displays how a lung collapse could be physically expressed

After we studied different ways of communicating the data and feedback, we combined the data into a hybrid artifact. Here, we explore the ways in which we can take diverse data inputs with a range of expressive needs, and translate them into a coherent method of communication. We explore the intersections of tangibility, visualization, and dynamic physicalization with the data derived from the professional medical system setting. In the next section, we describe the tangible hybrid designed for a critical healthcare context.

Tangible Hybrid

The tangible *Hybrid* (Figure 7, 8, 9) is an interface that embraces the humanization of data. Unlike GUIs, data is communicated and manipulated to the professional users through data physicalization. The interface translates the breathing graph to a dynamic shape that a user can access through one's peripheral vision. It is further assisted by the visual and haptic modality of breathing frequency to ensure that the professional users receive the necessary, precise feedback in this safety critical context. This physical data can further be manipulated through two stage manipulation. First, a rough adjustment by gently pressing the physical data (Figure 10). Second, a fine tune dial to adjust the precision (Figure 11) of value.

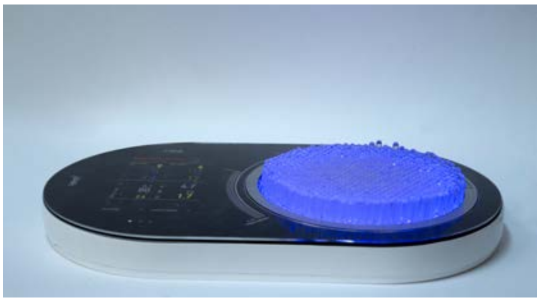


Figure 7: Tangible Hybrid normal pressure state

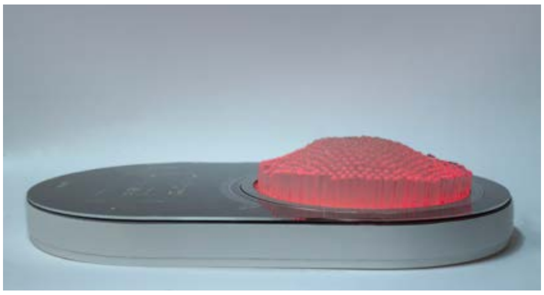


Figure 8: Tangible Hybrid high pressure stat

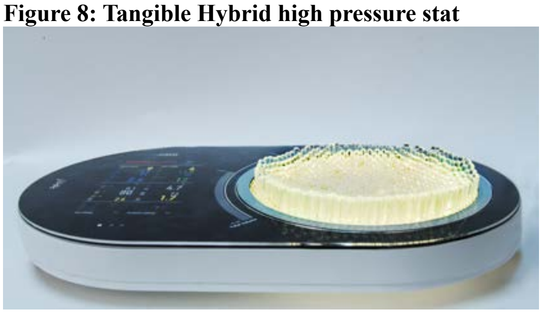


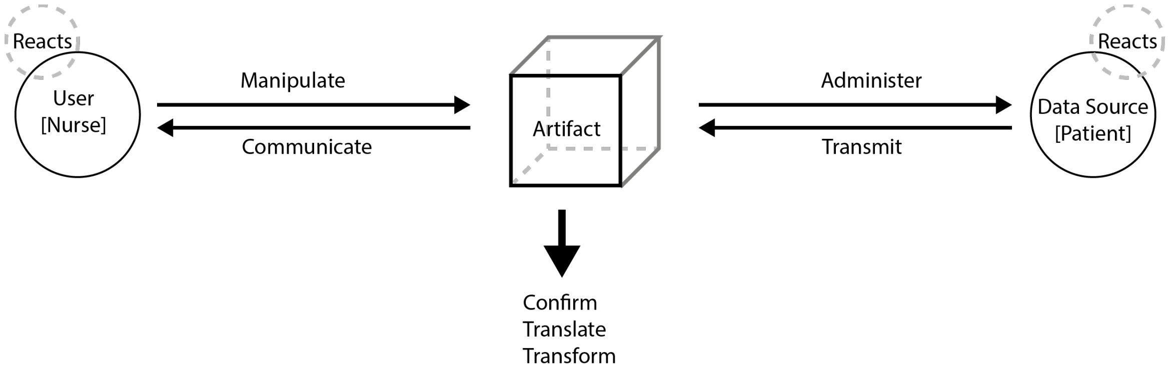
Figure 9: Tangible Hybrid low pressure state

Figure 10: Tangible Hybrid direct touch manipulation

Figure 11: Tangible Hybrid fine tune dial

Evaluation

Going further, we evaluated the interface on the basis of intuitiveness and interpretation. The focus group, consisting of professional anesthesia nurses, successfully accepted this interface, stating that this could be an excellent tool for caring for the patient in an intensive care unit long term. Some of the manipulation challenges, like direct contact, seemed debatable because of the hygiene in this context. Every device has to be sterilized before and after the operation. This requires detachability of tangible product from the base.



TOWARDS THE SYSTEM COMPLEXITY IN TANGIBLE INTERACTION

During the research on ventilation for anesthesia, we observed that the nurse(user) and patient(data-source) mutually interact and manipulate values through a machine(artifact). The nurse's action on the machine influences the patient. And the patient in turn influences the data displayed the machine. This displayed data prompts the nurse to take actions on machine. This creates a complex system involving multiple intelligent user interacting with data. (Figure 12)

Current use of graphical user interfaces hides this system complexity of interaction, reducing it into mere numbers and dials on the screen making it harder for the user in visualization, decision making, and manipulation.

DISCUSSION

Through the application of tangible interaction in a critical context, we encountered many design problems that helped us identify various research opportunities. These opportunities included the emotional meaning of data, communication, manipulation, dynamic affordance, and systemic complexity in tangible interaction. Among the research issues that we explored, we learned that when we look at tangible interfaces as a bridge between digital and physical world, it leads to issues in communication, manipulation, usability, scalability, and application. To solve this, we had two approaches. First, we solve each of these issues by zooming into each of them on a micro level. Second, we zoom out and understand the bigger picture. The method is still an open question to the research community.

CONCLUSION

We reflect on the nurse, patient, and machine in hospital ecosystem in the case study to understand the application of tangible interface in a context and address the challenges associated with it. Further, we realize that instead of treating TUIs as a bridge (between digital and physical world), we can start looking them as a part of an ecosystem in the larger context where multiple intelligent actors and artifacts mutually influence the outcome. In the future, we imagine the seamless collaboration between intelligent actors like Artificial intelligence(AI), environment and human in a cohesive system, where tangibles become the medium of communication. With the advancement of smart materials, we envision more of these smart interfaces, used in the professional user context.

REFERENCES

1. Djajadiningrat, T, Frens, J, Overbeeke, K, and Wensveen, S. (2004) Tangible Products: Redressing the Balance Between Appearance and Action, Personal and Ubiquitous Computing, 294-304
2. Alexander, J, Dragicevic, P, Hornbæk, K, Isenberg, P, Jansen, Y, Karnik, A, Kildal, J, Subramanian, S. (2015) Opportunities and Challenges for Data Physicalization, Natural User Interfaces for InfoVis, CHI 2015, Crossings, Seoul, Korea, 3228-3229, 3234
3. Bonanni, L, Hiroshi, I, Labrune J.B, Lakatos, D. (2012) Radical Atoms: Beyond Tangible Bits, Toward Transformable Materials. Interactions: People, Experiences, Technology, MIT Media Lab, 50

GLOSSARY OF TERMS

Alveolar pressure: The pressure in the alveoli of the lungs.The product of resistance to gas flow by flow at the airway opening

PEEP: Positive end respiratory pressure. A technique of assisting breathing by increasing the air pressure in the lungs and air passages near the end of expiration so that an increased amount of air remains in the lungs following expiration.

Partial Pressure: the pressure exerted by a (specified) component in a mixture of gases

Respiration rate: Frequency of breathing, recorded as the number of breaths per minute.

Tidal Volume: the volume of air that is inspired or expired in a single breath during regular breathing

Alveolar pressure. (n.d.). In Science Direct Online. Retrieved from

http://www.sciencedirect.com/topics/nursing-and-health-professions/alveolar-pressure

Partial Pressure. (n.d.). In Miriam-Webster Medical Online. Retrieved from https://www.merriam-webster.com/dictionary/partial%20pressure

PEEP. (n.d.). In Miriam-Webster Medical Online. Retrieved from https://www.merriam-webster.com/medical/positive%20end-expiratory%20pressure

Tidal Volume. (n.d.). In The Medical Dictionary Online. Retrieved from

https://medical-dictionary.thefreedictionary.com/tidal+volume