Tangible interfaces for tangible robots

Andrew Cynua Smith
CSIR’s Mende Institute
South Africa

1. Introduction

Various modes of tangible interfaces have been explored and researched. In this chapter we limit our look at tangible user interfaces to a subset of these. The subset is characterised by portability and no attached tethers, be they mechanical links or electrical wires. The subset does include tangible objects that are connected to a larger system for the purpose of relative position and orientation detection, if relevant. Such detection mechanisms include optical, magnetic, and radio means. Examples of optical detection are the use of fibre optics and a video camera. Magnetic detection utilises either the presence of a magnetic field, or the changes in such a field. Radio detection mechanisms include the use of the Global Positioning System (GPS) and radio frequency identification (RFID). Using electrically conductive pire provides another untethered system.

Electrical field sensing and the use of acoustic waves are also covered in this chapter. In our discussion we assume open-loop control of robot manipulators, that is, the user interface does not receive feedback from sensing subsystems. The user interface relies on other subsystems to check the inputs provided by the user interface with the actual position of the manipulator.

2. A Short Introduction to Tangible User Interfaces

If this section we introduce the novice to this existing mode of interfacing to technologies. We look at the properties of known Tangible User Interfaces (TUIs) and how they have been applied in the real-world. What are Tangible User Interfaces (TUIs)? The term TUI has been coined by Ulmer and Ishii in 1997 (Ulmer, 1995). This definition is somewhat restrictive in that the output is also reflected in the input device. An example of such a device is Tokoro's Tekobo. Tokobo is a physical device that will record the actions the user has taken on its various components. For example, if the user constructs a model dog and moves the various legs, the system will record the motions and replay them. It is quite possible to let the system modify the behaviour after being recorded, or allow a response even during the recording.

In this chapter we look at a broader definition of TUI, similar to the relaxation of TUIs by others (Holein, 2006). In the definition we address cubic objects that provide an input to
some system. The output is not manifested in the cubes as per the strict definition of TUI's. As applied to robot effectors, this implies that the output is visible through the change in the effector's state. For the purpose of this chapter we refer to the broad script of TUI's as given in Fishkin2006. In this broad script we are concerned with an "input event", some system that "senses" the event and somehow responds to it, and some form of feedback initiated by the system which is called an "output event".

We base our interaction role on those described elsewhere (Yanco, 2004). In the taxonomy of Yanco, five interaction roles are given. These are "a supervisory role", "an operator", "a bystander", "a mechanic", and "a bystander". The tangible interfaces we describe are best suited in the role of a supervisor. The supervisor constructs the series of actions that should be executed by the robot and then activates the program represented by the cubes. The underlying system does not simply execute a number of steps, but has the ability to change the execution sequence based on inputs received from the actuators, the environment, or another system (Fig. 1).

Some three-dimensional TUI's are manipulated in a two-dimensional plane. Other TUI's have been developed that also work in three-dimensional space, such as Tobeo, ActiveCubes, and SystemMecha. Tobeo can be used as an autonomous system. ActiveCubes are used to sense and interface with other systems.

![Generic tangible system diagram](image)

**Fig. 1.** Generic tangible system diagram

### 3. Why TUI and not GUI?

Ever since the electronic computer became a research tool the operator had to take care of the delicate input mechanisms available to interact with the computer. At first the mechanisms available were switches and paper tape. These were followed by magnetic tape and paper punch cards. At this time output mechanisms evolved from paper tape and lights, to the two-dimensional cathode ray tube (CRT) display. Yet these output mechanisms are still two-dimensional. The information displayed on these displays has progressed from only textual to the incorporation of graphical elements. Over time the Graphical User Interface (GUI) has become familiar to all computer users. Yet some users still insist that the textual interface suits them the best. They claim that they are the most productive with such an interface. At the same time these users also make extensive use of the QWERTY keyboard to interact with the computer. They are professional computer system developers and make little use of the computer mouse, claiming that the keyboard shortcuts they are accustomed to empower them more than using a mouse and the GUI. For the majority of computer users the GUI and mouse remain the most prominent interface to the electronic computer. There exists, however, a relatively new research field in which the manipulation of physical artifacts is considered as an alternative interface to the electronic computer. It can be argued that making use of tangible interaction with the computer, in addition to the GUI, increases the "bandwidth" available to a user for interacting with the computer. An increased bandwidth allows for faster interaction. The use of gross motor skills, in addition to the fine motor skills required for operating a computer mouse, might be more "natural" for some users.

**Fig. 2.** Graphical User Interfaces address the user's cognitive skills. Tangible User Interfaces also incorporate the user's motor skills (Hegewald 2009)

**Fig. 3.** TUI instantiations of GUI elements (Ulmer 1997)
In the physical world in which we use Tangible User Interfaces (TUIs), we can find similarities between the TUIs and the GUIs by extrapolating the two-dimensional screen to the three-dimensional physical world.

4. Limitations and Advantages of TUIs

TUIs have certain advantages and limitations compared to other technology interfaces. These advantages and limitations are discussed in this section.

4.1 Limitations

Tangible User Interfaces have a number of disadvantages over conventional Graphical User Interfaces. These include storage of the constructs sequence, the space required for the sequence, how to make it persistent (as one would save a file to a hard disk), how to document it and transporting the constructed sequence.

Fig. 4. Transferring TUI sequence can be difficult (Horn 2009)

4.2 Advantages

Tangible User Interfaces can potentially be designed to be intuitive for the novice user (Fig. 5), but potentially frustrating for an advanced user. A textual interface or an Iconic interface could be presented to the advanced users as a possible solution.

Fig. 5. Tangibles (Scharf et al., 2009)

5. Data Coupling Mechanisms

5.1 Magnetic

Magnetic detection is possible using either mechanical switches or solid state detection circuitry. Figures 6 and 7 illustrate a system called GameBlocks which makes use of mechanical "read" switches.

Fig. 6. GameBlocks (Smith 2007)  
Fig. 7. GameBlocks (Smith 2009)

5.2 Electrical contact

Electrical contacts rely on direct physical contact between two or more electrically conductive components. A few examples follow.

AlgoBlocks

AlgoBlocks makes use of wide electrical connectors to distribute the data through the system.

Fig. 8. AlgoBlocks (Tanaka 1995)

FlowBlocks

FlowBlocks distributes data using the same magnets that are used to keep the various components together.
Fig. 9. Flowboards are connected using magnets. The same magnets are also used to transfer data and power between the blocks. The inset shows three magnets at the end of one of the blocks. Magnets assist in aligning the blocks properly (Zuckerman 2005).

VIO controls
VIO controls make use of pins which consist of two parts each. One part runs along the inside of the other and is slightly larger than the outer sleeve. The longer length allows penetration to a second conductive layer which is located below the upper conductive layer. The sleeve makes contact with the upper layer only.

Fig. 10. VIO controls (Villar and Gellesen)

Fig. 11. The electrical configuration of VIO controls. (Adapted from Villar and Gellesen)

5.3 Optical: video camera from below
This approach makes use of bottom projection (Fig. 13) with the video camera placed below the work surface. A configuration like this is convenient as it eliminates obscuration of both the projection and video recordings (Fig. 14).

5.4 Optical: video camera from above
In the previous section an example in given of fiducial markers (Fig. 15) placed at the bottom of the object being tracked. Another configuration is with the fiducial markers placed on top of the object to be tracked (Fig. 16). Optional images are also projected from above the interaction surface.

Fig. 12. An example of the VIO controls being applied

Fig. 13. Using tangible tagged with fiducials to control and actuate. Visual feedback is provided by the projection below the transparent work surface (Adapted from Kalenichenko and Berenson)
Fig. 14. Tangibles with fiducials and bottom projection are used to control a music synthesiser in a system called "reactTable."

Fig. 15. Examples of fiducial marker types. The fiducial on the left is very compact. (Adapted from Keilharlruher and Bonnita)

When using Illuminating Light (Fig. 17), a software programme identifies the coloured dots and their patterns on the optical elements. A projector then adds additional information onto the work surface, such as the path of reflected light. This (Fig. 18) consists of a collection of interlocking pieces. Each piece has a unique optical pattern imprinted on the top which identifies the function of that piece.

Fig. 16. Top camera and top projection (Kern 2009)

Fig. 17. Illuminating Light (Underkoffler 1999)

Fig. 18. This tangible interface consists of wooden blocks shaped like jigsaw puzzle pieces (Kern 2009)

5.5 Optical: one dimensional

In contrast to the two-dimensional video camera communication mechanism described earlier in this chapter, we here present two examples of TUI systems that make use of a single light source that communicates between two blocks (Fig. 19, 20).
5.6 Acoustic sensing

The acoustic table (Fig. 21) consists of a number of acoustic transducers which are used to "illuminate" the surface of the interaction area. The objects to be detected contain circuits that respond to the "illumination" by transmitting infrared signals to a set of infrared detectors around the table.

5.7 Induction sensing

Induction sensing systems (Fig. 22) make use of low frequency alternating current flowing through a wire grid. The objects to be sensed contain their own inductive and capacitive circuits which resonate at a pre-determined frequency. If the sensing surface is stimulated at the same frequency at which the object to be sensed has been tuned, the object will be detected.
6. Other TUI’s

We have not covered the multitude of possible sensing and construction mechanisms. In this section we simply provide a few more interesting examples.

![Image](Image)

Fig. 24. Grid-restricted tangibles (Frazer 1996)

The following TUI’s are not restricted to a surface for assembly. They operate independently of a surface and can be manipulated in the hand of the user while in operation.

6.1 Tobopo

Tobopo (Fig. 25.) consists of a number of building elements, most of which contain electrical circuits.

Some elements serve as sensors, others as actuators. What makes Tobopo unique is that some building elements contain both a sensing circuitry and actuators. As an example, if the user rotates the shaft of a motor element, the Tobopo system can record that action and on command ‘play’ the action.

![Image](Image)

Fig. 25. Tobopo programming and replay (Raffel 2008)

6.2 SystemBlocks

SystemBlocks (Fig. 26.) consists of a number of objects with embedded electronic circuitry. These augmented objects are interconnected using electrical wires through which data flows.

![Image](Image)

Fig. 26. SystemBlocks are interconnected using electrical wires (Zuckerman 2004)

6.3 ActiveCube

ActiveCube (Fig. 27.) is a system comprising of various cubes, each containing an electric circuit specific to the cube’s intended function. The cubes are custom designed to serve as either sensors or actuators. Examples of sensor cubes are a sound processor, an infrared sensor, a gyroscope sensor, a tactile sensor, and an ultrasonic sensor. Examples of actuator cubes are a motor, a buzzer, a vibrator, and a light. ActiveCubes are snapped together using the four clothing fasteners on each of the six cube surfaces. These fasteners are also used for transferring data between the cubes.

![Image](Image)

Fig. 27. ActiveCube (Watanabe 2004)
7. Tangible Interfaces Research at the CSIR’s Merauke Institute

In the research described in the above sections, little or no consideration has been given to the costs involved in creating the tangible interfaces. A different approach is followed at the CSIR’s Merauke Institute. The Institute is located in the developing region of Southern Africa where access to funding is limited, perhaps more so than in developed regions where the research covered above is taking place. As a result, the cost of technology is considered a very important system component. To achieve the objective of affordable Tangible Interfaces for developing regions, the Institute explores various materials and technologies. In all its research to date, the Institute has made use of low cost electronic components for interfacing the tangible objects to toy robotic devices (Smith, 2008).

The approach followed at the Institute, which distinguishes it from the others mentioned, is that of leveraging commercial knowledge and the use of low-cost technologies. To this end, one of the research objectives is to develop a modular system in which various community members can collaborate in the construction of a robotic system using tangible interfaces. When realised, one train member will assemble a simple, low cost electronic circuit. In turn, another train member will design and craft Tangible Interface objects. The electronic circuit and the crafted object will then be integrated to form a Tangible Interface. This Tangible Interface can then be manipulated by the end user. The purpose of the electronic circuit is to sense the position and orientation of the tangible object and then send commands to a robot. Examples of robots used in the research include humanoid robots and LEGO cars (Fig. 28).

7.1 Technology

The sensing mechanism is common to all the prototypes described in this section. In these prototypes, the sensing of a Tangible Interface object is accomplished through a combination of low-cost Reed switches and permanent magnets. A number of Reed switches are mounted on a sensing platform and magnets are embedded inside Tangible Interface objects. When a Tangible Interface object is placed on top of the sensing surface, a pre-determined combination of Reed switches close. At the same time an electronic circuit senses the state of the Reed switches and sends appropriate instructions to a robot for execution.

7.2 Prototypes

Cubic - and rotational Tangible Interfaces prototypes are described in the following sections.

Cubic Interfaces

Initial research at the Merauke Institute made use of acrylic sheets. These were cut according to a profile which allowed assembly into a cube without the need for adhesives (Fig. 29). Low power laser facilities at a local FabLab (Cambridge, 2008) were of immense value in completing this task (Smith, 2006). As a side it can be noted that FabLab is a concept which originated at the MIT Media Lab with the objective of making advanced prototyping technologies available to communities in developing regions.

The second prototype was constructed from commercially available closed-cell foam squares. These squares are manufactured in large quantities for use in baby and toddler rooms (Fig. 30). The bright colours and soft texture afforded by these foam squares are ideal for young users of the Tangible Interfaces (Smith 2004).

Rotational Interfaces

A different sensor configuration was tested in the third and fourth prototype designs. In this configuration all tangible objects are identical in both shape and function, the difference being the spatial orientation of the tangible being manipulated. By changing the configuration of sensors inside the sensing surface as well as that of the embedded magnets inside the tangible, a configuration for sensing rotation was realised.
In the third prototype the properties of soft rock were explored. Using hand tools, the end user can easily shape the soft rock to create a personalized tangible (Fig. 31). This prototype has been dubbed "RockBlocks" (Smith, 2006).

"Dialando" is similar to RockBlocks, a tangible interface based on rotational information. This fourth prototype demonstrates the use of recycled materials in its construction. A tangible object is constructed by sandwiching low cost magnets between two discarded CD/DVDs and finishing the construction off with a section of discarded electrical cord.

Fig. 31. RockBlocks and Dialando

7.3 Problems and solutions
A common problem experienced in various degrees is that of aligning the tangible object with the sensing surface. If the alignment is slightly out, the tangible object will either not be sensed or will be sensed incorrectly. The fourth prototype described above is an attempt to address this problem.

In an effort to reduce alignment problems a neodymium magnet was incorporated at the centre of the tangible object (Fig. 31). A matching magnet was also positioned in the center of the sensing surface. Being of opposite polarity, the two magnets pull the tangible object into place when approaching the sensing surface, thus eliminating most of the misalignment problems experienced in the other designs.

7.4 Future work
In the design of the Dialando prototype, most of the alignment problems have been addressed through the addition of magnet-pairs. What still needs addressing is how to limit rotation of the tangible object to discrete angles. It is anticipated that this can be accomplished using a similar mechanism as that implemented for solving the misalignment between the sensing surface and the tangible object.

8. References

Tangibles interfaces for tangible robots


Patterson, J. M. (2005), Mechanical Constraints as Common Ground Between People and Computers, PhD dissertation, 2005, MIT.


Timoshenko Beam Theory based Dynamic Modeling of Lightweight Flexible Link Robotic Manipulators

Malik Loundiri
École Nationale Supérieure d’Informatique Algérie

1. Introduction

In recent years, establishing more and more explicit, complete and accurate dynamic models for the special category of flexible link manipulators has been a formidable challenging and still open problem in robotics research.

This chapter is devoted to a methodological presentation of the application of Timoshenko beam (TB) theory concepts to the mathematical description of flexible link robotic manipulators dynamics, as a more refined modeling approach compared to the classical Euler-Bernoulli (EB) theory (EBT) which is the conventionally adopted one.

Compared with the conventional heavy and bulky rigid robots, the flexible link manipulators have their special potential advantages of larger work volume, higher operation speed, greater payload-to-manipulator weight ratio, lower energy consumption, better maneuverability and better transportability. However, their utilization incurs a penalty due to elastic deformation and vibration typically associated with the structural flexibility. As a consequence, the motion planning and dynamics modeling of this class of robotic manipulators are apparently made extremely complicated, as well as their tip position control.

The complexity of modeling and control of lightweight flexible manipulators is widely reported in the literature. Detailed discussions can be found in (Kaneko et al., 1986; Balch & Takaneda, 1989; Bock, 1990; Yurkovitch, 1992; Bock, 1993; Junge & Xiong, 1995; Canudas de Wit et al., 1996; Moulton et al., 2000; Benoist et al., 2002; Roberts et al., 2002; Wang & Cao, 2005; Benoist & Ver, 2004; Detry & Berard, 2006; Tejño & Aïd, 2008).

In order to fully exploit the potential advantages offered by these lightweight robot arms, one must explicitly consider the effects of structural link flexibility and properly deal with (active and/or passive) control of vibrational behavior. In this context, it is highly desirable to have an explicit, complete and accurate dynamic model at disposal.

In this chapter, we aim to present the details of our investigations concerned with deriving accurate equations of motion of a flexible link robot arm by the use of the TB

In the first part of this work, a brief review of different beam theories and especially that of Timoshenko is given. Then, based on the TB, the emphasis is essentially set on a detailed description of the different steps, allowing the obtaining of accurate and complete