# Multi-touch Table with Image Capturing

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## Abstract

This text reviews the state-of-the-art of technologies for multi-touch control and taking photographs or video recordings through the screen. Furthermore, the work describes development of a prototype device combining a multi-touch screen in a table setup with the ability to take pictures through the viewing area.

**Keywords:** Human-Computer Interaction, Multi-touch, Switchable Diffuser, Scanning

## 1 Introduction

In recent years, the development of computer technology experienced rapid expansion into all various areas of industry and everyday life. Hence the importance of natural ways of interaction between humans and computers in all forms is growing strongly. There is a demand for interfaces that are intuitive (and thus the learning curve is steep for their use) and which allows users to employ theirs potential and do not needlessly slow down their activity. Assessment, which user interface is appropriate in different use-cases is usually matter of research.

The goal of this work is to implement a prototype of an interactive device for such research. Specifically, it is an interactive table that combines a touch screen with the ability to take pictures (scans) of objects through the imaging area.

Following scenarios illustrate possible motivation for developing this method of interaction. For instance, imagine a designer, who draws a draft for a new logo on a piece of paper. He comes home to his interactive device, puts the paper on the screen and the drawing is scanned. He can instantly interact with his draft in a digitalized form using the computer. Of course, he could use scanner, but the case mentioned is more straightforward and intuitive approach.

Another example: interactive kiosks are located around a large hospital. A patient comes to see a doctor. She has no idea about the actual position of the doctor's office. But she has an invitation card with a barcode. She comes to the interactive kiosk, which instructs her to place the card on the surface of the kiosk. After that, the barcode is recognized and she is navigated to the right place.

Finally, tangible object, such as cell phones, cards, chessmen, etc. lying on an interactive surface, can be recognized easily and they can be used as controls.

However these examples are only suggestions. Proper research must be done to determine, if these and other similar use-cases are really usable and worthwhile. The purpose of our prototype is to allow such research.

## 2 Related Work

This section discusses several technologies, which can be used for our device. The first part focuses on a multi-touch control. The second part summarizes technologies for capturing image from the screen direction.

### 2.1 Multi-touch Input

Touch input surely is a promising way to bring more naturalness and real behavior into the human–computer interaction. That is why there has been a great attention recently [1]. Interest in touch technologies among the public increased in the 2006, when Jefferson Han introduced his multi-touch display based on FTIR technology [2] (see 2.1.4). After that, many people built their own tables with multi-touch screens. In the beginning of the 2007, Apple introduced theirs multi-touch cell phone named *iPhone*. It used capacitive technology. The *iPhone* affects whole segment of the mobile phone industry. In the same year, *Microsoft* introduced the *Microsoft Surface* – a coffee table with a multi-touch screen. This is based on the optical method *Diffuse Illumination*, which is described later in 2.1.4.

In general, touch input provides not only information about positions of contacts with the surface, but also about the relative pressure or angle of the touching object (especially a finger) [1]. Technologies vary in abilities of different objects detection. Some can detect only fingers, and do not allow usage of a stylus or other objects. Some technologies allow tracking of close objects, which are not really touching the display [1]. Finally, there can be a demand to identify the objects lying on the display. It can be achieved by reading special patterns (tags) glued to the bottom of these objects. A summary of particular technologies that can be used for touch input follows.

#### 2.1.1 Resistance Based Technologies

Resistive touch surfaces consist of two conductive layers with a tiny gap between them. When pressing the upper

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flexible layer, it contacts with the bottom one. There are two basic methods to determine the contact position [3].

The **four-wire technology** drives a voltage gradient into the first layer and a voltage is measured on the other. This is used for calculating the first coordinate. The second coordinate is acquired analogically by changing the function of the respective layers.

The second method (the **five-wire technology**) attaches the voltage always to the upper layer and measures the current from the corners of the bottom layer.

There follows a list of general advantages and disadvantages of resistance based methods:

**Advantages**

- any type of object (materials) can be detected
- resistant to dirt, dust, water or light pollution
- low power consumption

**Disadvantages**

- only about 75% to 85% transparency
- degradation of the upper layer over the time (five-wire technology is more durable)

### 2.1.2 Capacitance Based Technologies

Capacitance based technologies are available in two basic variants too [4].

**Surface capacitive** touch panels consist of thin conductive coating on a transparent glass. From each side of the panel electrodes maintain a uniform electric field across the conductive layer. As human fingers (or other conductive objects) are capable of exhibiting electric fields, touching the panel results in a small transport of charge from the electric field of the panel to the field of the touching object. The value of electric current drown from the corners is measured with corresponding sensors. After that, microprocessor calculates an exact position of the touch based on the values measured.

**Projected capacitive** touch surfaces contains very thin grid of wires or electrodes between two glass layers. The grid behaves as a matrix of capacitors. When touched, capacitance forms between the finger and the sensor grid. The touch location can be computed using the measured electrical characteristics of the grid layer. Depending on the implementation, this technology can detect more touches at once than surface capacitive technology.

**Advantages**

- higher transparency than methods based on resistance (especially the projected capacitive method)
- high resolution and accuracy
- high mechanical robustness (especially the projected capacitive method – it can be covered with up two centimeter protective layer)
- resistance to dirt, dust, grease
- higher reliability than methods based on resistance

**Disadvantages**

- higher price (especially the projected capacitive method)
- detects only conductive materials (but it can be an advantage – unintended touches by clothes are ignored)

### 2.1.3 Acoustic Technology (Surface Acoustic Wave)

In this technology, ultra-sonic waves are induced and directed from piezoelectric transducers in orthogonal directions over the surface [3, 4]. When touched, the measured signals are changed, which is used to calculate a position of the contact.

**Advantages**

- no transparency limitation
- robustness of construction
- high resolution
- resistance to intense light

**Disadvantages**

- limited to fingers and soft objects
- affected by dirt and dust negatively
- limited count of touches detected simultaneously

### 2.1.4 Optical (Infrared Light) Based

Most optical methods are quite easy to implement and much cheaper than capacitance based methods. This determines theirs usage in many, often home-made or academic, prototypes [5]. Additionally, some optical technologies allow more detection modalities as mentioned in the introduction of this section (see 2.1).

Optical methods are usually based on capturing the surface in infrared light (IR). There are several techniques, which differ in the arrangement and in the corresponding features. In general, optical based methods have the following advantages and disadvantages:

**Advantages**

- very good transparency
- multiple touches detection (depends on a method)
- detection of tags and close objects (some methods)
- resistance to water, degradation
- relatively low price and simple manufacturing process
- recognition of arbitrary objects, shapes (most methods)

**Disadvantages**

- requires complex computation for touch detection
- sensitive to intense ambient light

In the following, individual optical methods are described briefly.

***Light Grid (LED Light Plane)***

This technique is very similar to the mentioned acoustic method. Instead of acoustic waves, there is a grid of infrared light over the surface, emitted by LEDs located around [3]. When touched, the infrared ray is interrupted, which is detected by sensors on the edge and evaluated as a touch.

**Advantages**

- simplicity
- resistance to dirt and dust
- can be mounted on a conventional display

**Disadvantages**

- cannot recognize arbitrary shapes, tags and close (but not touching) objects
- cannot recognize pressure
- lower resolution
- bad scalability (many sensors)
- limited count of touches (may occur occlusion)

### *Laser Light Plane (LLP)*

The infrared light from a laser is driven through dispersive lens just above the surface, so it generates a light plane [6]. When touched, the light reflected from the tip of the finger is captured by a camera located below the active surface (see Figure 1) and the position of touch can be determined.

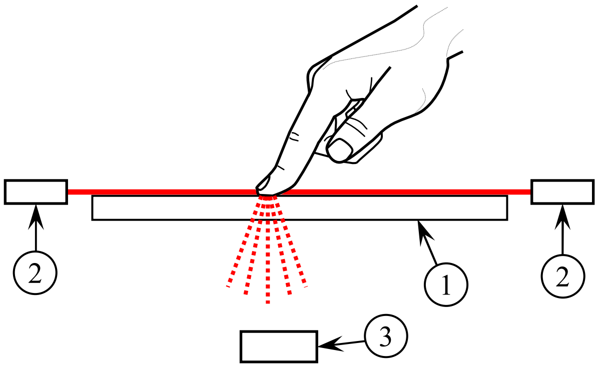


**Figure 1: Laser Light Plane: (1) glass or plexiglass, (2) IR laser, (3) IR camera**

**Advantages**

- simplicity
- relatively cheap

**Disadvantages**

- cannot recognize arbitrary shapes, tags and close (but not touching) objects
- cannot recognize pressure
- sometimes limited count of touches (may occur occlusion)

### *Frustrated Total Internal Reflection (FTIR)*

This technology – used by Jefferson Han [2] – is based on a principle of total internal reflection: Touch panel made from acrylic glass (plexiglass) is illuminated in infrared from edges of the surface. If the refractive index of the surface panel material is higher than the refractive index of the surroundings and the light incidence angle at the boundary is higher than the critical angle, total reflection occurs, and all light spreads through the material. When an object with a higher refractive index touches the surface, some light leaks, which is captured by an infrared camera behind the panel. The acquired video stream is used to determine position of touches.

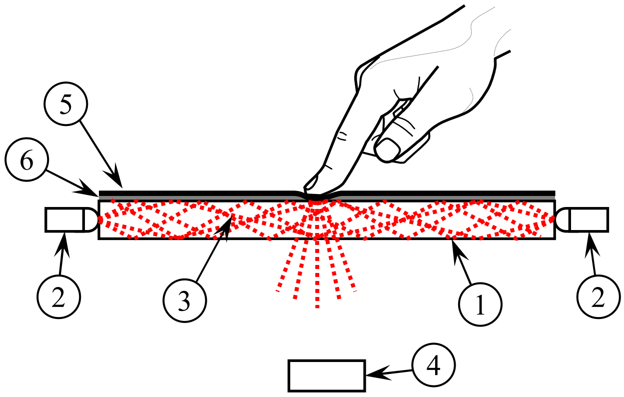


**Figure 2: Frustrated Total Internal Reflection: (1) acrylic glass, (2) IR LED, (3) total internal reflection, (4) IR camera, (5) projection layer, (6) compliant layer**

There must be a good coupling between the touching object (finger) and the acrylic glass to trigger a FTIR effect. It can be achieved by pressing hard to the surface, but this decreases ease of use. Dragging makes the FTIR effect even weaker [4]. Therefore, there is usually another layer applied – a compliant layer. It is a thin layer of soft translucent material, which is put (or coated) between acrylic and a top layer. The upper surface (see Figure 2) is a diffusing layer, used as a projection plane. While touching, the upper layer couples with the acrylic and triggers stronger FTIR effect. Moreover, it allows interaction with objects of arbitrary material – there are no constraints for the refractive index of the touching object, when using compliant layer. Finding an appropriate material of a compliant layer and the way of its application (in the right combination with a projection layer) is a crucial step of the implementation [7, 8, 4].

**Advantages**

- recognition of multiple touches and any shapes
- good scalability
- high accuracy and robustness
- can detect pressure indirectly (by size of the touched area)
- with a good compliant surface, it can be used with something as small as a pen tip
- an enclosed box is not required
- usable on non-planar surfaces
- cheap

**Disadvantages**

- size – depends on viewing angle of the camera(s)
- requires a LED frame
- requires acrylic (regular glass cannot be used)
- cannot detect close objects (not touching)
- complex implementation of the compliant layer

*Diffuse Illumination (DI)*

This method is based on uniform diffuse illumination of the surface from the bottom [4] (see Figure 3). An infrared camera captures light reflected from objects on the surface. The diffusing layer (which can be used as a projection surface) is important for object recognition. Blurriness of reflected objects corresponds to their distance from the diffuse surface. The reflection is most sharp and bright when an object is in direct contact with the surface.

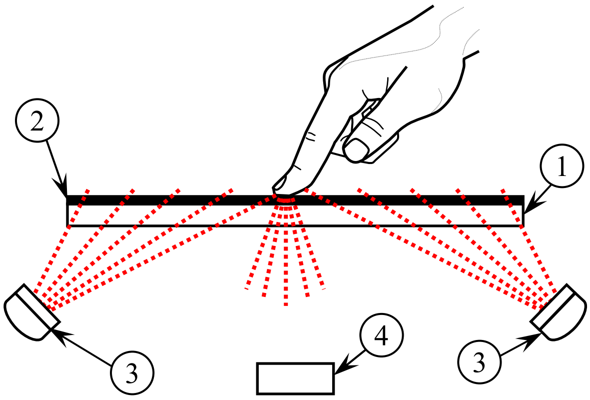


**Figure 3: Diffuse Illumination: (1) glass or plexiglass, (2) diffusing layer, (3) IR illuminator, (4) IR camera**

**Advantages**

- can recognize multiple touches as well as various shapes
- objects near to the surface can be recognized without direct contact with the surface
- can be used to recognize objects using special tags glued to their bottom
- good scalability
- unlike FTIR, DI does not require special acrylic glass and allows for adding another protection surface
- simple design

**Disadvantages**

- size (dimensions depends on the viewing angle of the camera)
- uniform infrared illumination of the surface is complex
- lesser contrast than FTIR
- can be affected by ambient infrared light

This method can be combined with the already mentioned FTIR method. In the way the accuracy of detection can be improved.

*Diffused Surface Illumination (DSI)*

Diffuse Surface Illumination method resolves the main issue of previously mentioned DI method – the uniformity of infrared illumination [4]. DSI requires special material of the projection surface. As shown in Figure 4, this material contains small particles that behave as microscopic mirrors that reflect infrared illumination from the sides uniformly out of the surface. Objects above the surface reflect this light back to the camera similarly as in the DI method.

**Advantages**

- similar as the already mentioned DI method
- uniform illumination is easier to achieve
- switch over to the FTIR method is simple (replacement of the surface glass)

**Disadvantages**

- size (dimensions depends on the viewing angle of the camera)
- requires a frame of the LEDs
- requires special glass *(Enlighten)*
- less contrast than DI (micro-mirrors reflects the light partially down to the camera)
- can be affected by ambient infrared light

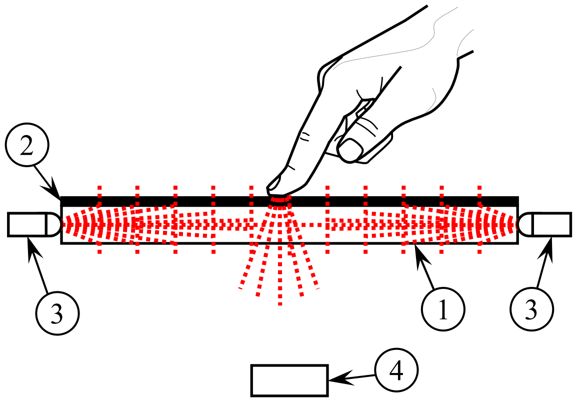


**Figure 4: Diffused Surface Illumination: (1) *Endlighten* plexiglass, (2) diffusing layer, (3) IR LED, (4) IR camera**

*Matrix of Infrared Transceivers*

Optical methods mentioned above require space behind the touch surface to accommodate the infrared camera. Size of the device depends on optical properties of this camera, in front of all on the viewing angle. This issue can be to some point resolved by using mirrors. If there is a demand for a flat device, matrix of infrared transceivers can be used. [4]

Principle of this method is following: Infrared emitters and sensors are uniformly placed out under the surface of touch panel (eventually LCD panel). Sensors detect light that is reflected from objects on or near the surface. This method has been used in system *ThinSight* [9] and in the new version of Microsoft Surface 2.0 [10].

**Advantages**

- thin form factor
- supports recognition of objects that are near to the surface (similarly to DI and DSI)

**Disadvantages**

- complex manufacturing process
- problematic scalability
- limited resolution

***Computer Stereo Vision***

Unlike already mentioned approaches, this method requires two cameras that capture the surface from two different places. Difference of these two images is used for computation of position of the objects (on or near the surface) [11]. The principle is similar as human stereoscopic vision.

Advantage of this method is that is supports recognition of objects (and gestures) that are more distant from the projection surface. However, this method requires complex calibration and processing and the surface has to be transparent.

## 2.2 Scanning Through the Screen

This section describes possibilities how to gain a visual input. Current technologies provide a simple way how to capture images of the user, even from different angles. To capture an image directly from the position of projection surface is more complex. The motivation is for example to enable users to keep the eye contact during a video-call or to capture images of objects that are near to the projection surface and therefore cannot be captured from its sides.

Currently there are more possibilities how to resolve this issue [12]. One of them is to use a semi-transparent mirror, but it has significant drawbacks. It requires additional space in front of the display for the mirror and it prevents access to the display surface. Moreover, prevention of unwanted reflections requires shielding.

Transparent display would be a better option. An LCD panel is not appropriate, because its transparency is only about 8% [13]. An OLED display is more promising, but it is currently too expensive, especially in sufficient dimensions [14]. Another option is to adapt rear projection to support this feature.

There is a market-available material – called *HoloScreen* or HOPS (Holographic-Optical Projection Screen) – which allows rear projection, while maintaining transparency [11]. It consists of holographic film, which redirects light depending on an angle of incidence [15, 16]. Problem is that the projected image is partly reflected back to the camera, so it interferes with the captured picture. Theoretically, it can be subtracted by the software, while the projected image is known. The reflection can be also decreased by using an antireflective film. The image mixing effect can be avoided by capturing in infrared light, if the application allows that. Last option is to use a shutter in front of the projector and closing it synchronously with camera shooting.

Another option is to use a projection surface that can be switched to a transparent mode [17]. This can be achieved for example by using a *Polymer Dispersed Liquid Crystal* (PD-LC) panel, which is used as a privacy glass. This material is diffusive translucent but not transparent in the initial state; therefore it can be used for the rear projection. It can be electrically switched to a transparent state. In this mode, pictures can be taken directly through the surface. The switching time is around 100 milliseconds. If there is a need for faster switching (e. g. for video capturing), an advanced technology called *Polymer Stabilized Cholesteric Textured Liquid Crystal* (PSCT-LC) can be used. This technology allows the state change in less than 0.5 milliseconds [18].

HoloScreen is used in *TouchLight* system [11] in combination with stereo-vision multi-touch technology. The switchable diffuser has been already used in several research works, usually with the PD-LC [17, 19]. The faster material has been introduced in *SecondLight* project [18]. The transparent state is not used for image capturing there (although the authors suggest that for the following work). In *SecondLight*, a second image is projecting through the screen onto another surface.

# 3 Our Solution: Interactive Table

This section describes our implementation of an interactive table. It summarizes our goals and main design steps in both hardware and software perspective.

## 3.1 Implementation Goals

In order to explore the mentioned methods of interaction, we decided to implement them in our own prototype. Our objective is to combine a multi-touch screen and the ability to take high-resolution photos through the projection plane in one device. Multi-touch displays become very popular these days. However the scanning feature is not so common in current implementations and looks promising from the interaction point of view (as have been discussed in chapter 1).

## 3.2 Hardware Design

The optical based technologies provide an easy way to construct a multi-touch screen in constraint (not industrial) conditions. These technologies are relatively cheap and moreover facilitate wider range of capabilities. We have chosen the technology of *rear diffused illumination* (DI), which can be easily combined with the intended scanning feature. Picture is projected by the projector from the rear on the diffusing plane.

The uniformity of IR illumination is achieved by using two *Infra Red LED Light Bars* provided by *Environmental Light* [20] and proper installation along both sides. These LEDs operates in 850 nm with high flux and wide beam angle. The capturing camera is equipped with IR-pass filter on same wavelength. Indirect ambient light does not strongly disturb the function thanks to the LED brightness, uniform illumination and a narrow band.

As mentioned, the ability of taking photos through the screen can be achieved in more ways. Technology with switchable diffuser (PD-LC) is simple, easy to construct, and does not require large form factor.

Placement of the main components is depicted on the Figure 5. The surface is illuminated by the two infra-red LED illuminators. The modified (IR-cut filter replaced by

IR-pass filter) PS3 Eye camera is capturing image in infra-red and the video-stream is transferred to the computer using USB. There is another high-resolution camera Cannon EOS 400D for taking photos (with IR-cut filter installed), the camera is also controlled via USB. This camera is located eccentrically (near the projector) to avoid reflections from the projector. For taking a photo, the diffuser is switched to the transparent state for a short time and the projector lightens the scanned area. The switching is achieved by using a remotely switchable socket, which is controlled from the computer over RS-232 [21].

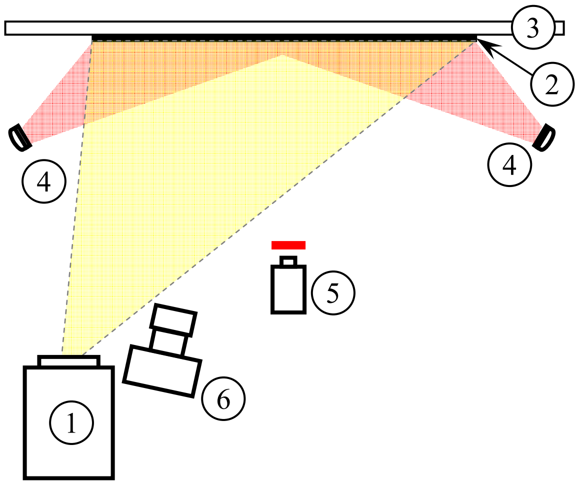


**Figure 5: Prototype design: (1) projector, (2) switchable diffuser, (3) transparent plexiglass, (4) infrared illuminators (850 nm), (5) camera with IR pass filter (850 nm), (6) high-resolution photo camera**

## 3.3 Software Design

After the multi-touch control became popular, several open-source implementations have been developed [22]. These solutions process video stream and calculate positions of touches. There are also frameworks and Software Development Kids (SDK) to simplify development of multi-touch applications. Some promising implementations are discussed in the following section.

### 3.3.1 Computer Vision

The first group of software solutions takes video-stream as an input, analyzes it and recognizes touches. The touch events are posted to the next application layer.

**Community Core Vision** (CCV) [23] is implementation by community *NUI Group*, under continuing development. It is intended for any camera-based optical technology. It can recognize fingers, and since version 1.4 also objects and tags. CCV is implemented in C++ for *Windows*, *Linux* and *MacOS*. Recognized touch events are sent to application layer through TUIO protocol [24] over UDP or as a native XML for *Adobe Flash* applications.

**reacTIVison** is simpler than CCV. It is developed in C++ by *Music Technology Group* at the *Universitat Pompeu Fabra* in Barcelona [25]. The TUIO protocol has been primarily designed for this software. Unlike CCV *reacTIVision* was focused for tags recognizing, but there is a support for fingers detection since version 1.4.

**Bespoke Multi-Touch Framework** is complex multi-touch framework implemented in C# by Paul Varcholik for *Windows* platform [26]. However, it is not further developed.

### 3.3.2 Application Frameworks

The next software layer processes the data about touches and provides support for developing multi-touch applications.

Project **MultiTouchVista** [27] developed by Daniel Danilin takes messages from TUIO protocol [24] (or inputs from multiple mice) and translated them to standard *Microsoft Windows* multi-touch event messages. It provides multi-touch driver for *Windows 7*, allowing utilize the embedded multi-touch support of this system *(Windows Touch)*. This allows using *Microsoft Surface Toolkit* and ensures the compatibility with other multi-touch devices including *Microsoft Surface 2.0*.

**Microsoft Surface Toolkit** [28] is a SDK for developing multi-touch applications for *Windows Touch* (native multi-touch interface in *Windows 7*). The toolkit contains controls, templates and application examples using application programming interface (API) of the *Windows Touch*.

**PyMT** is a *Python* module for developing *OpenGL* applications with multi-touch support [29]. It can be used on *Windows*, *Linux* or *MacOSX*, implements TUIO client and provides a large set of controls and tools usable in multi-touch applications. Several interesting examples are included.

### 3.3.3 Additional Software

Operating system **Microsoft Windows 7** was chosen because of its native support for multi-touch and compatibility with other layers and large set of similar devices. *Windows Presentation Foundation* framework version 4.0 contains tools for developing applications for *Windows Touch*.

*Sony*, the manufacturer of the **PS3 Eye** camera does not provide driver for personal computers. Fortunately, **CodeLabratories** developed one and provides it for free [30]. *CodeLabratories* also implements SDK allowing full control of the camera.

The high resolution photo camera used can be controlled via SDK, which is provided by *Canon* on explicit demand [31]. The current version of **Canon EOS Digital SDK (EDSDK 2.7)** has been used in our prototype.

**The PD-LC controlling** through the switching socket must be implemented. We have to ensure the right synchronization with **image capturing**. The .NET platform has been chosen as an implementation environment and C# as a programming language. Final implementation should be a dynamic library with a simple application interface (API).

### 3.3.4 Software Choice

Based on the previous analysis following software components has been chosen:

- operating system: **Microsoft Windows 7**
- camera driver: **CL Eye Platform Driver** [30]
- touch recognition: **CCV 1.4** [23]
- event handling: **CCV 1.4**, **MultiTouchVista** [27]
- switching controling: **our C# implementation**
- photo camera driver: **Canon SDK** [31]
- synchronization between taking photos and diffuser switching: **our C# implementation**
- additional application frameworks: **Microsoft Surface Toolkit** [28], **PyMT** [29]

Figures 6 and 7 describe links among these components.

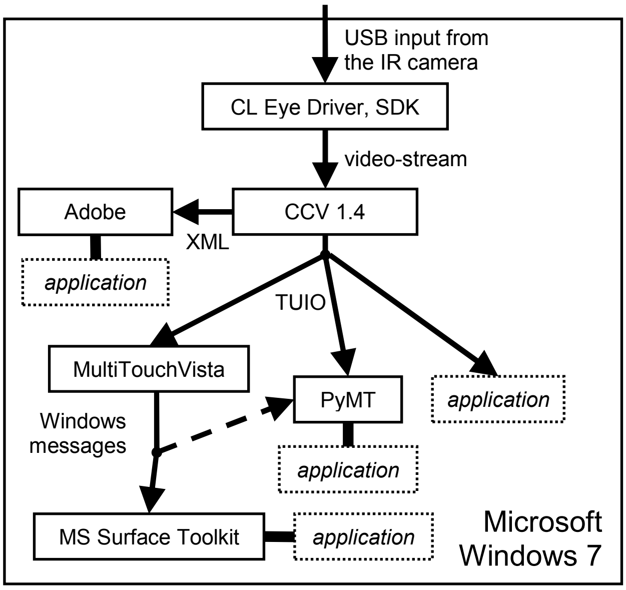


**Figure 6: Scheme of the multi-touch software components**

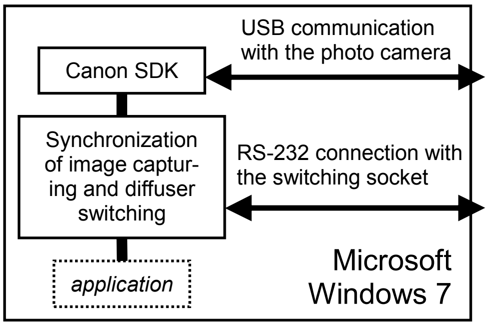


**Figure 7: Scheme of the capturing software components**

## 4 Results

This work has two main achievements. The first one is a summary of technologies for touch input and scanning from the screen direction. The second achievement is a functional prototype of a device which implements both multi-touch screen and image capturing through the display. The multi-touch input is achieved by using CCV as shown in Figure 8.

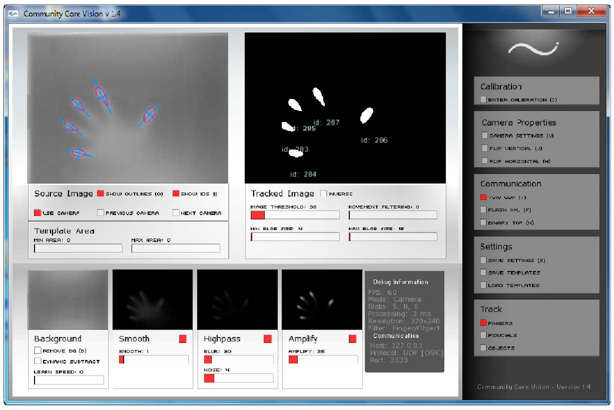

**Figure 8: Touch recognizing by the Community Core Vision – version 1.4**

Figure 9 shows the proposal and the final prototype.

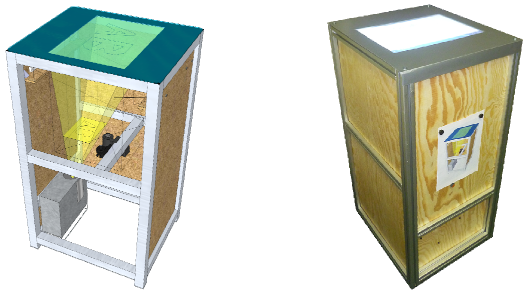

**Figure 9: Our device: (left) sketch, (right) final prototype**

## 5 Conclusions and Future Work

During the work it became clear that the issue of the touch input technologies is large. There are many approaches, the main are summarized in this paper. The aim of implementation has been fulfilled, and relatively cheap device was built.

The implemented device provides additional possibilities comparing to other multi-touch tables. Applications utilizing the scanning feature are subject of the immediate future work.

Future work should be focused on the software optimization and interaction design. Usability of implemented features should be evaluated. Additionally, barcode recognition can be added.

An automatic trimming of captured image would be very useful. In the current version, the whole display is lightened, while an image is captured. This is because the captured object should be well illuminated for a good picture. But the light can be shined directly to user's eyes, if no object occludes. If a good detection of object were implemented, the illumination could be focused only to the object.

There are also many possible improvements in the hardware implementation. The height of the device can be reduced by using front-surface mirrors and/or short-throw projector. Larger screen can be made (possibly with multiple cameras). Other form-factors of interactive systems (beside table) could be investigated.

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