



# What is the future of touch screen technology?

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## Abstract

Around half of global population owns touch screens but they encounter problems meanwhile. Modern life will be easier and more convenient with touch screen technologies, if four main problems can be solved including improvements and applications of multi-touch technology, accessibility of gloved fingers, touch screens designed for the blind and alternative sustainable materials. The research is carried out to deducing the future development of touch screen technologies. It discussed history of touch screen technologies, how do they work, problems of using and corresponding solutions. After analysis and comparisons of references, four predictions about touch screens are made. Firstly, capacitive touch screen technologies will continue to dominate the market until a disruptive new technology takes over. Secondly, Frustrated Total Internal Reflection (FTIR) will be widely applied in museums and workplaces. Thirdly, variety touchscreen-related products will increase. Lastly, silver nanowire touch screens are expected to be applied on large screens while graphene touch screens will be implemented on portable devices.

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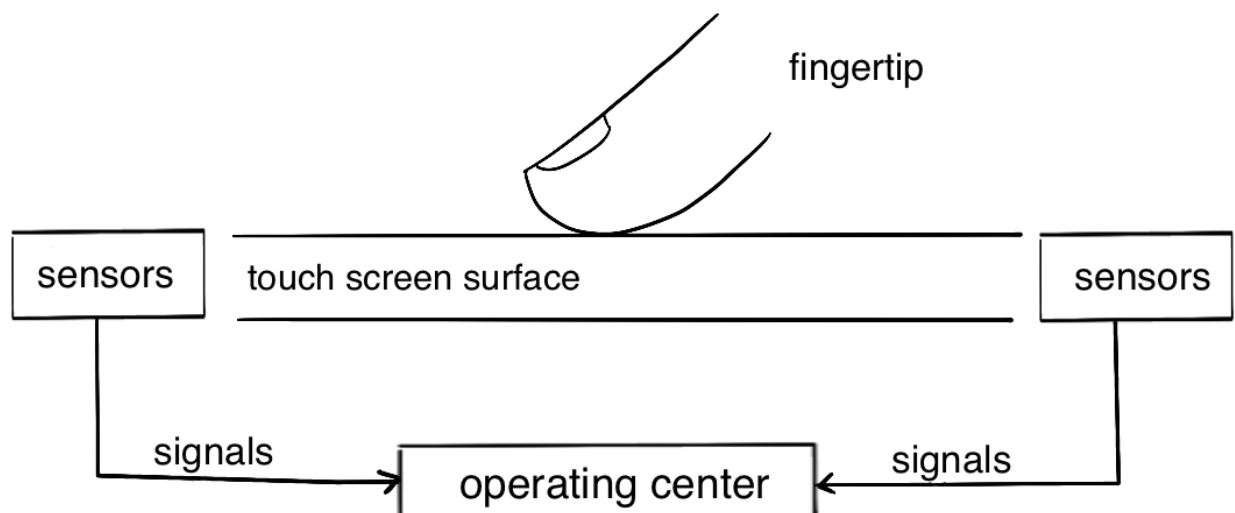
# 1 Introduction

## 1.1 Importance of touchscreens

Around half of global population own one or more touch screen devices [1]. Although touch screens have developed for over 50 years [2], there is still room for improvement. Sometimes, the device cannot respond to multiple inputs at the same time, which is really annoying in multiplayer games. Additionally, people can hardly operate their mobile phones when they are unwilling to take off gloves on a cold day. The disabled like blind people cannot use visual-based electronic devices which gradually covered most of our lives so they may encounter loads of problems in daily life. Finally, resource sustainability is a huge global issue related to every users. Indium, a main mineral used in touch screens, is predicted to run out in 3 years [3]. The following research is carried out in order to deducing the future of touch screens technologies by finding the solutions of these issues.

## 1.2 Basic physics of touch screens

Touch screens allow users to operate directly with fingers or flexible equipment, such as styluses, instead of keyboards or mouses which are mechanized [4]. Referring to Figure 1, touch screens mainly depend on various sensors, like infrared receivers, to detect whether touched or not. Coordinates are sent to the computer operating center. Touch screens can perform differently due to different sensors [5]. For example, capacitive touch screens cannot identify inputs other than fingertips and unique styluses because their sensors rely on charges on human bodies [6], while infrared touch screens accept all kinds of inputs as long as energy can be absorbed by them [7].



**Fig. 1.** Sensors will send coordinates to the operating center if touched.

## 2 Literature review

### 2.1 History of touchscreens

The first touch screen invented was a capacitive screen in 1956 [2]. The purpose of this invention was to increase the efficiency of human operations on machinery so to optimise man-machine communication [8], [9]. However, this technology was not popularized and put into mass production immediately as relatively more suitable alternative, resistive touch screens with more affordable prices and higher durability, came up soon [2].

In 1971, Sameul Hurst invented the fresistive touch screen. The most obvious improvement in his invention is elimination of obstacles for writing on tablets, compared to the conventional writing which requires writing instruments, such as pens [10]. He got the inspiration while he was teaching at the University of Kentucky, where numerous charts needed to be read through. During the time, he started to consider a new coordinate measuring system [11] and accidentally found a way to control electric current with pressure [2]. Although he was not supported by the school, he firmly believe it would be a monument to development of human-computer interface [2]. Around 6 years later, the technology was patented [12] and Sameul Hurst set up a company named Elographics to produce electronic devices with the technology. Siemens Corporation then asked for a collaboration on the development of a curved glass sensor, which later was called touch screen [11]. The Elographics have specialized in touch screen invention for approximately 50 years and a new Elo touch screen is installed every 21 seconds around the world based on official statistics [13].

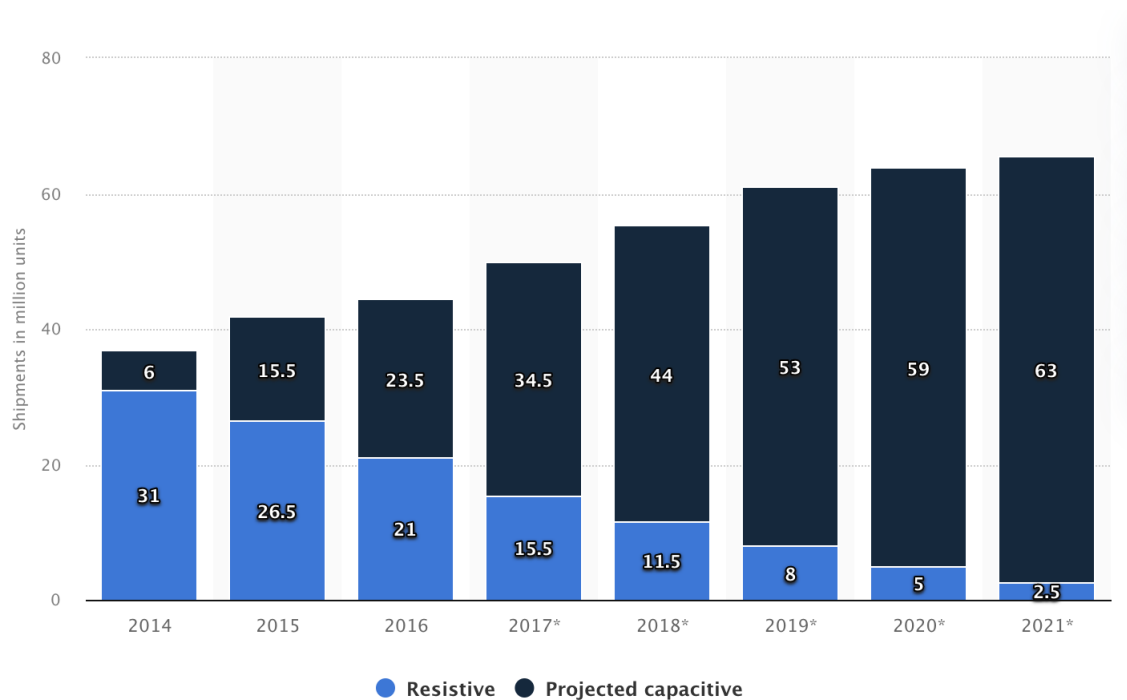
In 1972, a group from the University of Illinois Urbana-Champaign, including Frederick Ebeling, Roger Johnson and Richard Goldhor, invented a touch screen containing pairs of infrared emitters and detectors arrayed on x and y dimensions [14]. The invention aimed at promoting educational field [14] and latter they designed Programmed Logic for Automatic Teaching Operations (PLATO). It was the first system for educational assistance that students are allowed to operate on their terminals [15], such as answering questions by touching anywhere on devices [2].

As the development of touch screen technologies, more businesses saw commercial opportunities [2]. In 1983, Hewlett-Packard Company created the earliest touch screen product for sale. It is known as HP-150 or "Magic" and costed \$2795 originally. Introduction of HP-150 led a triple increase in revenues of personal computers [16]. In 1998, a company called FingerWorks came up which focused on exploration of multi-touch technologies [17]. Although their products received good feedback from the public, they still went through a rough time and eventually were taken over by Apple in 2005 [17]. Apple then made use of these advanced technologies on smartphone development and the first iPhone with fully touching control published in 2007 [2].

Based on Figure 2, the total sales of two types of touch screens (resistive and projected capacitive) experienced a noticeable increase from 37 million units in 2012 to 65.5 million units in 2021. Besides, projected capacitive kind gradually replaced resistive screens and became dominant over 7 years.

### 2.2 How touch screens work

Touch screens rely on sensors to detect touching location, before transmitting signals to the computer operating system, where algorithms are applied. There are mainly four types of touch screens that contain various transducers and achieved functions in different ways [5]–[7].



**Fig. 2.** Unit shipments of touch panels for automotive applications worldwide from 2014 to 2021 (in millions), by technology [18].

### 2.2.1 Resistive touch screen

Resistive touch screens are popular nowadays due to their relatively lower prices [7]. The touch overlay contains a flexible and conductive layer on the top and a rigid but resistive bottom layer. Figure 3 shows that the inner surface on both of them is coated with Indium Tin Oxide (ITO) that is conductive and able to control the extent across each layer when voltage is applied [7]. While top layer is pressed, it will bend inwards and create a complete circuit with the resistive layer so that a little current is generated. After that, the location will be transmitted to the touch screen controller, where central unit will process the data [6].

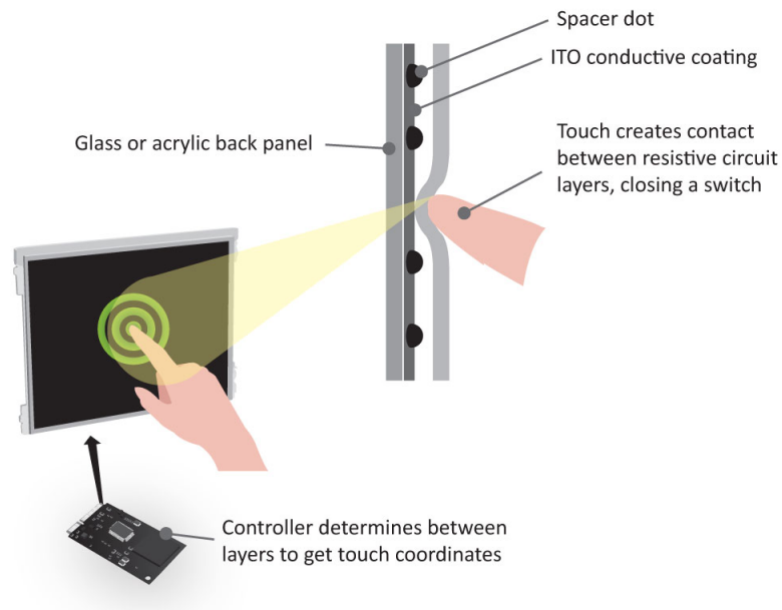
However, due to double layers, resistive touch screens badly perform in clarity and transparency. 75 % of original intensity can penetrate through its multiple layers [7]. Durability is also a problem. The conductive layer is likely to be damaged by sharp objects and the whole device is unable to work properly [20].

### 2.2.2 Capacitive touch screen

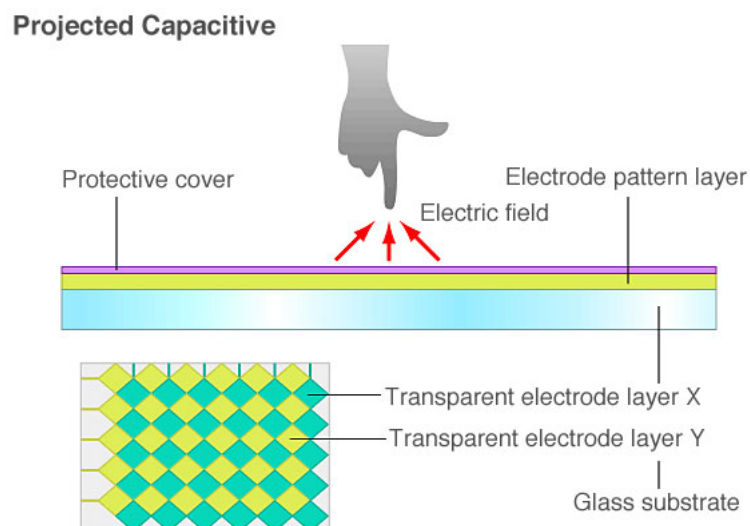
Current Apple products employ capacitive touch screens [5], which mainly uses ITO that is able to store charges on the panel. When an area is touched, charges are dispersed due to static charges on the user's fingertip [6].

The capacitive touch screens could be divided into two categories, projected and surface capacitive touch screens. Two layers of ITO, transparent electrode layer X and Y shown in Figure 4, are used in the projected capacitive touch screen and they are arranged perpendicularly [21]. The electric field will be affected by external charges, such as human bodies [6]. It means the tablet could make response even if it is not touched [21].

Surface capacitive touch screens only have a single film of ITO, which is illustrated as transparent electrode film on Figure 5. Touch points are observed by change in capacitance



**Fig. 3.** Resistive touch screen will form electrical contacts if touched [19].



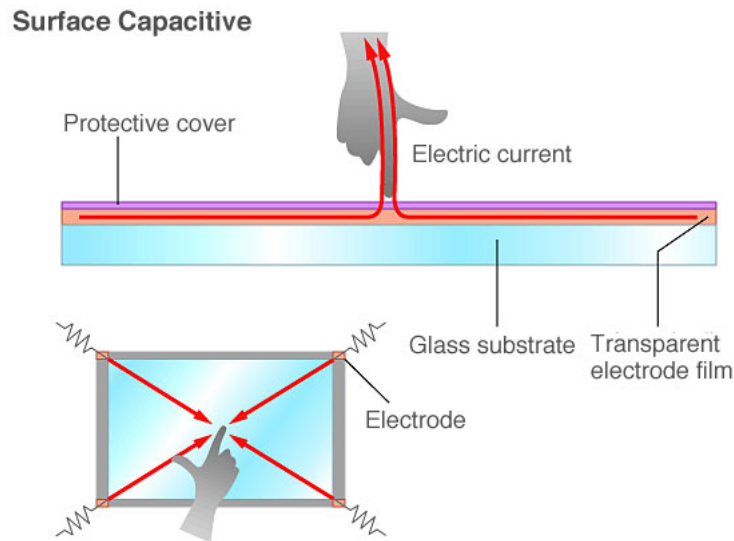
**Fig. 4.** Electric field of projected capacitive touch screen will be affected by charges on fingertips [21].

through electrode located at four corners [6]. While a conductive material comes close to the panel, the circuitry could detect the current change and send the signal to the processor [7].

Excellent clarity and high durability of capacitive touch screens gain a lot of popularity. Unexpected inputs, including liquids, dirt, grease, are unlikely to affect them [7] so it is not essential for users to clean them up frequently.

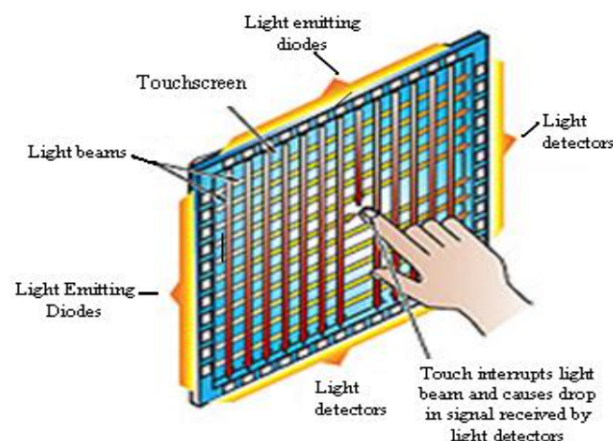
### 2.2.3 Infrared Touch Screen Technology

Infrared touch screens use infrared emitters and detectors to locate contact of the user on the screen. Infrared LEDs matched with photo-detectors are placed on the edges of panels as



**Fig. 5.** Conductors change current in the surface capacitive touch screen [21].

Figure 6 shows. If a user's finger is touching the screen, a significant reduction in detector intensity will be seen and the exact position will be processed in the central unit [7].



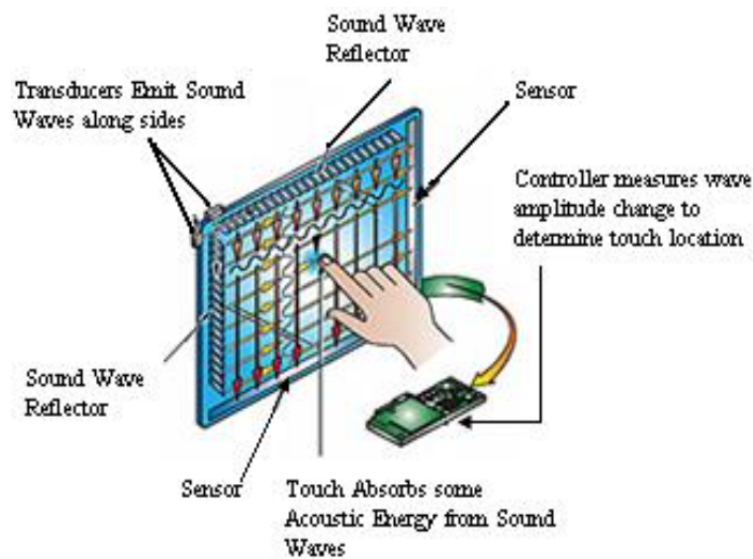
**Fig. 6.** Infrared receiver will recognise touching points when it does not receive infrared [7].

Because of reliance on infrared rather than static charges on human bodies, any kind of input that could block infrared waves is able to be responded by infrared touch screens, including stylus and gloved hands. Additionally, it is pretty flexible and versatile for a range of applications [6]. Users could simply install an extra devices with proper infrared grid where infrared are displayed at x and y axes shown as Figure 6. Multi-touch is available in infrared touch screens because waves can partially penetrate the touching point, in other word, intensity of infrared waves could be further decreased by touching on the same axis.

#### 2.2.4 Surface Acoustic Wave Touch Screens

Surface acoustic wave (SAW) touch screens, shown in Figure 7, are one of the most advanced technologies. SAW use sound waves as transmitters instead of electricity or infrared waves. Firstly, the controller will send electrical signals to transmitting transducers where signals are converted into ultrasonic waves. Then, waves will be reflected to receiving transducers [6].

Same as infrared, energy will be absorbed by touching objects so that certain events would be stimulated [7].



**Fig. 7.** Surface acoustic wave will be partially absorbed by fingertips, which could be detected sensors [7].

Because of no extra layer covered, SAW touch screens perform well in resolution and light transmission. However, dirt, dust or water in the surroundings are able to enter the device since it is not completely sealed [7].

## 2.3 Problems with touchscreens

Touch screens technologies have been developing for about 50 years [12]. Users, however, still encounter several problems, including gloved fingers, the blind and material sustainability [22]–[25] as well as multi-touch, a technology that allows one or more users to operate with multiple fingers [22].

### 2.3.1 Needs for Multi-touch Technologies

Multi-touch has been applied in daily routines already, which really benefits people's life in terms of enlargement and rotation of images. Multi-touch technologies allow users to arrange virtual pictures just like physical objects [26].

Availability of multi-touch is highly required in other applications, especially in modern museums where large scale of touch screens are displayed in order to illustrate theories or exhibits better, whereas, it have to support inputs from multiple visitors [27]. As a result, engagement of visitors could be enhanced [27]. Taking kids as an evident example, they prefer to come up to exhibits enabled interactions but they are rarely allowed touch and participate in terms of traditional displays [23].

As well as in museums, teamwork efficiency can probably be improved by multi-touch [28]. People are provided chances to collaborate and control devices at the same time. Information gaps, the difference in extent of knowledge usually caused by inefficient communication [29], would be effectively alleviated [28]. This is because of the same device supporting multi-touch they are using and cooperators would not disturb each other [28].

In general, advanced multi-touch technologies can be used in demanded occasions mentioned above and majority of consumers could benefit from it and live a easy life [22], [23], [27], [28].

### 2.3.2 Gloved fingers

Users may find that touch screens are unable to work while wearing gloves, which would be tough for public devices, such as automated teller machines (ATMs) [24] where convenience and sanitation are demanded.

The main factor of this problem is thickness of ordinary winter gloves, which is generally around 5mm [25]. However, this range exceed the controllable distance of capacitive touch screens that are mainly used in portable devices nowadays [25].

As well as thickness, materials of gloves also affect the effectiveness of response. Capacitive touch screens rely on the conductivity of human bodies but leather, wool cotton and rubber, common raw materials of gloves, are insulate. This is basically because their relative permittivities are lower than air [25]. Relative permittivity is an indicator that reflect to what extent matters could store charges compared with vacuum . The greater the relative permittivity is, the easier the charges transmit. Based on Table 1, capacitive touch screens work better with bare fingers than others.

**Table 1**

Materials and relative permittivity

Material	Relative Permittivity	Sources
Vacuum	1	[30]
Air	1.00054	[30]
Rubber	3	[30]
Cotton	2	[25]
Human body	70	[25]

### 2.3.3 The Blind

As the popularization of touch screens, the public has more chance to contact with this technology. Blind people, however, are generally becoming isolated [31] because of following three main problems.

Firstly, most of touch screens only have visual-based feedback, like change of color or leading to a new page. Secondly, users need to identify contents displayed on the screen before making decisions. Thirdly, selecting items, such as buttons, also need visual ability [31].

The sole visual reminder is the fundamental reason of these issues. People with low vision could be engaged by receiving non-visual output, involving timely audio or tactile feedback as soon as panels are touched [31], [32].

### 2.3.4 Sustainability of material

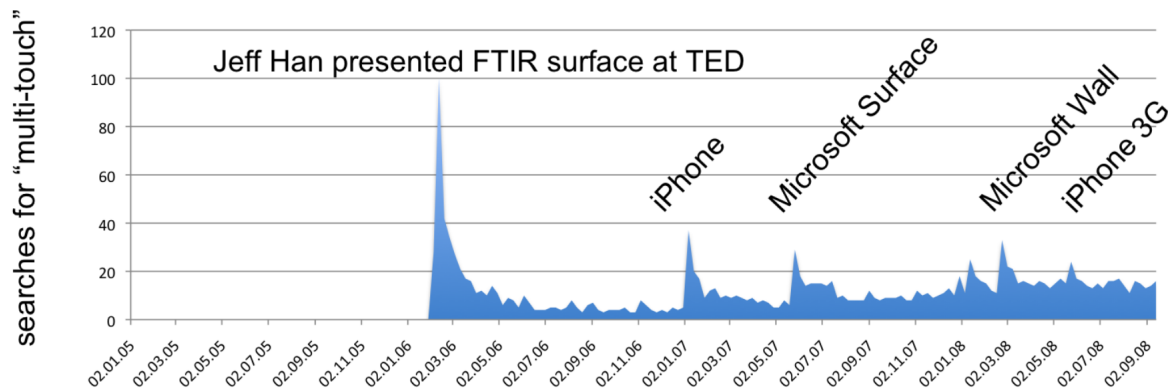
Indium is a key mineral used in touch screen manufacture [7] but it is a nonrenewable resource as well [33]. It is estimated that there are approximate 50 kilo-tonnes of indium around the world but only half of them could be exploited due to limitations of mining technologies [34]. The distribution of indium is pretty spread out. Only small amount of indium can be found in tiny traces so mining them widely is not worth considering [33]. Independent indium mine is not discovered yet so they are mainly extracted from blend ore [35] with 40% to 50% wasted during the process. As a result, 15 to 16 kilo-tonnes could be put into production [34]. A prediction from 2014 claimed that indium would run out in 10 years or less if the consumption is not controlled [3], [36].

Hence, a sustainable alternative with good optical transparency, conductivity and stability is extremely required [37].

## 2.4 How people trying to address the problems

### 2.4.1 Frustrated Total Internal Reflection

Multi-touch technology is firstly mentioned by Jeff Han on a TED talk [38] and from then on multi-touch become a heated discussion topics refer to Figure 8. He presented the screen with Frustrated Total Internal Reflection (FTIR) and showed how convenient they are [39].



**Fig. 8.** Popularity of Search Term "Multi-touch" [38]

FTIR is based on optical total internal reflection [38]. It is an interesting phenomenon only occurs when light ray transmit from a region with higher refractive index to a region with lower refractive index and the incident angle must be smaller than critical angle [40]. Refer to Figure 9, infrared emitters and receivers located at both end of the device and a camera is installed underneath projection surface coated with acrylic where total internal reflection happens. When one touches the surface at which refractive index changed, light will escape instead of following previous patterns, which will be observed by the camera [38].

Based on this fundamental structure, many software technologies are invented for detect more than one inputs but the basic idea is the same. FTIR tracking pipeline is a typical example. Areas without any intensity change are firstly filtered off [38]. Noticeable bright spots are found by high-pass filter that selecting waves by their frequencies [41]. Finally, those spots are converted into two-dimension coordinates [38].

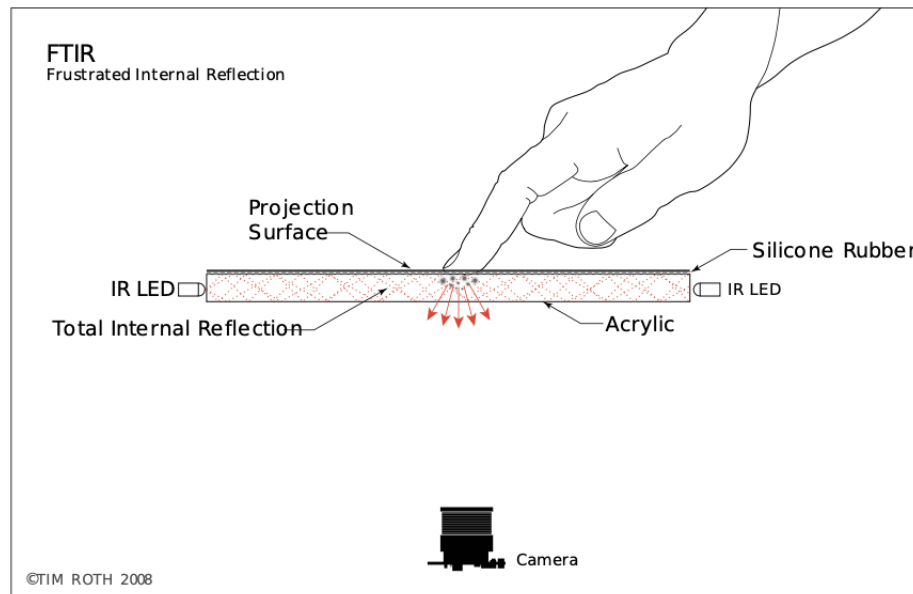
### 2.4.2 Conductive gloves

In order to solve the issue of no response to gloved fingers, the basis is to make the textile capable to store or transmit electrons [24], [42]. Gerald Leto and San Jose invented special leather gloves with metal back coating to make them conductive. This solution does not affect original properties of gloves, such as softness or waterproof characteristics [42].

Adding carbon black into ingredients is another solution [24]. Carbon black is a semi-conductor and allow materials like rubber and leather to be conductive [43]. Therefore, they can be used in touch screens operations.

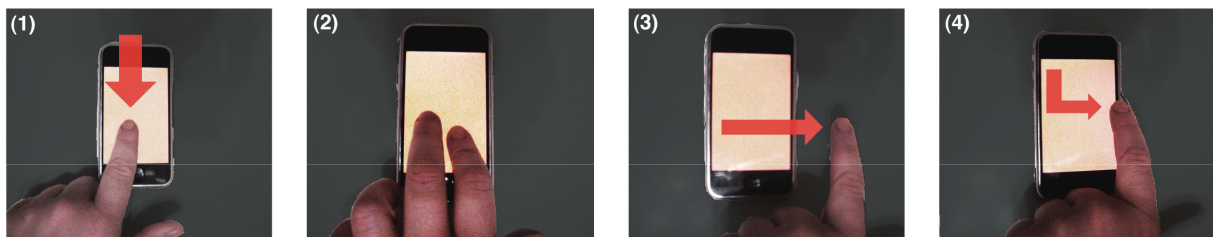
### 2.4.3 Slide Rule

Slide Rule is a software application designed by Shaun K. Kane and his team in order to help people with visual problems to operate touch screens. The main difference between Slide Rule and normal touch screens is that Slide Rule output audio as feedback rather than images.



**Fig. 9.** FTIR

Also, the operating gestures are presupposed and unique, to be more specific, one particular gesture matches a defined meaning. For instance, Figure 10(4) shows that users need to draw an "L" on the screen which means checking details of songs [31].



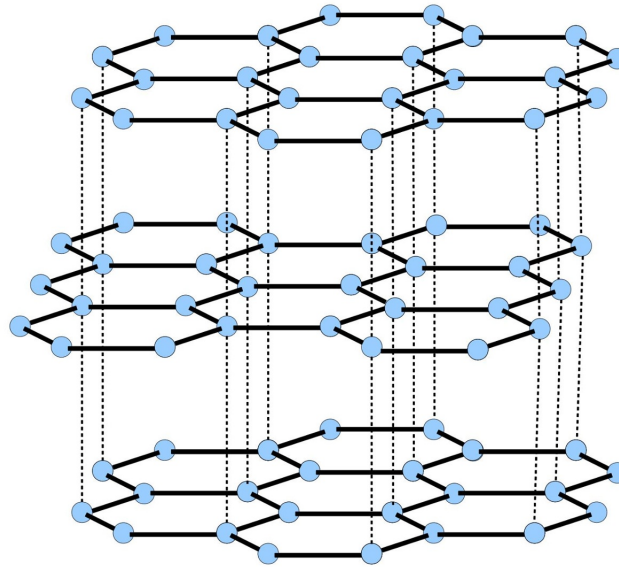
**Fig. 10.** Four gestures of Slide Rule operation: (1) Sliding down with one finger is used to check browse lists; (2) Tapping with the second finger could select items; (3) A flick gesture is used to switch between songs; (4) Scanning with a finger in an L-shape is used to browse detailed information of songs, such as musical artists and song names [31].

The team did a survey about user experience of both traditional touch screens system, Pocket PC [44], and Slide Rule. Participants are asked to complete three tasks, which are playing a given song, dialing a given contact and checking a given email. The result shows blind people completed tasks more quickly with Slide Rule but sometimes made mistakes [31].

#### 2.4.4 Graphene Touch Screens

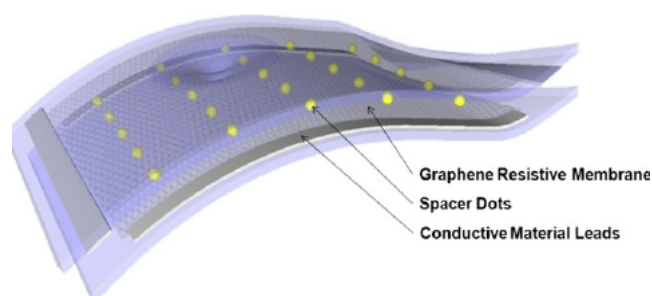
Graphene is considered as an alternative of indium tin oxide which has two main advantages. First of all, its atomic structure is a 2-D hexagonal shape and absence of chemical bonds between layers allows them to slide across each other [45]. Refer to Figure 11, each blue sphere represents a carbon atom and lines connecting atoms are chemical bonds, while dash lines between layers are weak attraction forces which could be broken easily. Hence, its malleability allows graphene to be easily transformed into a thin film with the thickness of only one carbon atom [46]. It is almost completely transparent and absorbs only 2.3% of light, in other word,

the graphene touch screen will perform a better in displaying. Additionally, graphene is a less scarce and much cheaper material than ITO [46].



**Fig. 11.** The structure of graphene provides it good malleability [47].

The manufacture process of graphene touch screens is pretty similar to the ITO resistive touch screens because the basic structure is almost the same but made up of different materials if you compare Figure 3 and Figure 12. Therefore, graphene touch screens could be put into mass production without other preparations [48]. Graphene touch screens are more durable than traditional touch screens due to the ductile and soft graphene, which means people are unlikely to break screens of their mobile phones [48]. Moreover, graphene touch screens are even able to be rolled up to become more portable [46].



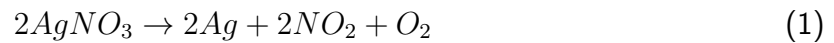
**Fig. 12.** Structure of graphene touch screens which is similar to the resistive touch screens made by ITO [49].

#### 2.4.5 Silver Nanowire Touch Screens

Due to the sustainability issues, a major component of touch screens, substitutes are highly demanded [37]. Silver nanowire is the next best choice because of its excellent conductivity and transmittance [50], [51].

Silver nanowire (AgNW) can be manufactured through various method, including photo-chemical reduction, hydrothermal method and template techniques [50], [52]. Hard template

method is the most common. Carbon nanotubes (CNTs) are filled with silver nitrates and produce AgNW with the presence of an electron beams [50]. Refer to chemical Equation 1, Silver nitrates are decomposed into silver, nitrogen dioxide and oxygen. Both  $\text{NO}_2$  and  $\text{O}_2$  are gases, allowing only Ag remains in the CNTs to form AgNW [50].



AgNWs will be fabricated to form transparent conductive films (TCFs). Then, TCFs will be sandwiched with hard-coat to form a transparent conductive films so that it is able to replace ITO layers of touch screens [51]. Benefits of this material is high malleability, which indicates curved touch screens are accessible [50]. Furthermore, ITO material is too fragile to be support large-scaled touch screens while AgNW touch screens are suitable for large devices [53] including touch screens used for presentation.

### 3 Discussion

There are four main types of touch screens mentioned above and each of them have their own advantages and disadvantages. Based on Figure 2, projected capacitive touch screens progressively take up majority of the market share. It is expected the trend would continue before the next innovation.

Problems encountered by users can be partially solved by current technologies. FTIR technology can satisfy the need for multi-touch technologies [38]. It is predicted to be widely implemented in occasions involving museums and workplaces to support relatively large amount of users. However, cellphones do not need that much inputs because mobility is their biggest advantages and their size is usually smaller than screens used in presentation, hence, excessive inputs are uncomfortable for operation. Therefore, I suppose FTIR technology is going to frequently appear in the future but unlikely to be applied in devices with smaller scale.

Conductive gloves can operate a public touch screen like an ATM [24], [42] while maintaining hygiene which is pretty significant during the COVID-19 pandemic. The production of these gloves is similar to traditional gloves but an extra process of adding carbon black [42] or coating metals [24]. The difference of user experience between conductive gloves and ordinary gloves is less likely to be recognized by consumers because additional ingredient can hardly affect the properties of gloves [42]. Overall, the invention of conductive gloves could perfectly deal with the accessibility of touch screens in winter or in the public. However, not all of users will buy the product but the innovation provide an option to a certain amount of users who need this kind of gloves. For example, outdoor photographers and people who value sanitation a lot are potential customers of conductive gloves. Moreover, touch screens, in my opinion, would promote demands for peripheral products including conductive gloves and styluses. Related industry will gradually increase and be diverse as the change of customers' needs.

In terms of devices designed for blind people, Slide Rule is a novel system [31]. The blind are able to be engaged in the touch screen operations through the Slide Rule. However, they must memorize the meaning of each gesture and all types of command and operations are presupposed. This innovation betrays the initial purpose of touch screen, which is simplifying operation of electronic devices and help users to get rid of fixed inputs like keyboards [4]. Inventions for the disabled should be paid more attention to. A easy design is being required to improve the disabled lives. My suggestion would be a special touch screen which could immediately speak out what the user touched and support a unique way of input to confirming the option such as double click.

Material sustainability is the last issue shown in this essay. Indium, as a by-product of blende ore, is going to be used up within 10 years at most [3], [36]. Graphene and AgNW are potential substitutes. The graphene is malleable, durable and has high light transmittance, supporting the curved screens but it is so soft [45] that cannot be applied in large devices. The AgNW is a fresh technology which allows the achievement of curved touch screens and silver nitrates are the raw materials instead of those scarce resources [50]. However, it is much more expensive than graphene. Hence, I believe AgNW-based touch screens would be widely applied in museums and schools where large-scaled touch screens are essential for displays and presentations as the development of mining technologies and the decline of cost of silver. Graphene, a relatively cheaper material at present, will replace ITO in the production of mobile phones in order to increase their portability.

Based on analysis above, there are overall three anticipations about the future of touch screen technologies. Firstly, projected capacitive touch screens will continue to dominant touch screen market. Secondly, developed FTIR technology will be widely installed in museums and workplaces but will not be applied on small-sized devices. Thirdly, touchscreen-related industry will increase in diversity. Lastly, AgNW touch screen technology will be applied on large-sized devices while graphene will replace the role of ITO in cellphone production. As for touch screens for blind people, there are still space for development and inventors and designers could put more efforts on them.

In terms of limitations, the research consulted 53 references in total which is insufficient for predicting the future development of touch screen technologies objectively. Study focused on current development of touch screen technologies should be deeper and more comprehensive, especially designs for blind people. Moreover, four main problems of touch screen operation is analysed but there is still other common issues encountered by users that are not involved, such as not available with wet hands. I would do a survey in the preparation to know more about popular issues in the field and specify the direction of the research, leading to an efficient and targeted research phase.

## 4 Conclusion

The research discussed four main problems in the touch screen use, which are demands for multi-touch technologies, inaccessibility of gloved fingers, lack of consideration for the blind and material sustainability. Each of them were provided with a possible solution which could help with improving of user experience. All of the solutions could deal with problems properly except the Slide Rule designed for the blind which cannot operated by users effectively.

My predictions about the future of touch screens are as follows:

1. Capacitive touch screen technologies will dominate touch screen markets due to their excellent performance in clarity and durability as well as direct interface between machine and human until a disruptive new technology takes their place which should be more durable and affordable.
2. FTIR technology is going to be widely implemented in places where large amount of users could operate a huge-scaled touch screens, including museums and workplaces rather than cellphones.
3. More touch screen related products will be launched in touch screen markets such as conductive leather gloves.

4. In terms of material, AgNW touch screens will be popularised on large touch screens as indium is running out within 10 years, while graphene touch screens will be applied on cellphones because of its durability and cheaper price.

These anticipations will lead to a promotion in economic development by expanding touch screen market because of diversifying variety of both touch screen types and peripheral products.

The research should consider more references so that the result would be more objective and credible. If time permits, a questionnaire about the user experience and problems of touch screens will be set up in order to collect the primary data which makes the statement of future direction more convincing. As well as a questionnaire, the research will continue to find out suitable solutions about touch screens facing the disabled.

The initial aim of touch screens is contributing to educational areas but later they are produced for commercial purpose so greater number of users is an attractive factor to companies like Apple and HP. Hence, they are hardly concentrate on designs for the disabled due to limited amount of suitable customers. It is suggested that touch screen designers should pay more attention on life of the disabled.

In general, the invention of touch screens can be seen as a milestone, which significantly changed people's lifestyle. Expansion of touch screen markets and progress in multi-touch, peripheral products and raw materials will be noticeable and valuable, continuously benefiting all touch screen consumers.

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