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The Art of Tactile Sensing: A State of Art Survey

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Abstract

This paper describes about tactile sensors, its transduction methods, state-of-art and various application areas of these sensors. Here we are taking in consideration the sense of touch. This provides the robots with tactile perception. In most of the robotic application the sense of touch is very helpful. The ability of robots to touch and feel the object, grasping an object by controlled pressure, mainly to categorize the surface textures. Tactile sensors can measure the force been applied on an area of touch. The data which is interpreted from the sensor is accumulated by the array of coordinated group of touch sensors. The sense of touch in human is distributed in four kinds by tactile receptors: Meissner corpuscles, the Merkel cells, the Rufina endings, and the Pacinian corpuscles. There has many innovations done to mimic the behaviour of human touch. The contact forces are measured by the sensor and this data is used to determine the manipulation of the robot.

Keywords: Tactile sensors; robotic sensors; tactile sensor applications.

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1. Introduction

Till a few years ago, the uses of robotic devices were limited to the manufacturing plants. As the technology advanced, these robots have made a significant way into human life [1].

A sensor that can detect information via touch can be termed as tactile sensor. Tactile sensors find interesting use in various Mechatronics devices. The two most significant application areas that grabbed attention are industrial automation and robotics. This was due to the contact interaction of the sensor, which is the basic feature of any physical control system. There are various other applications of tactile sensors. These include use of tactile sensors in agricultural units, medical field, food processing industries and other service industries.

The use of tactile sensing technology is growing fast and becoming more and more useful day by day. A major application of tactile sensors in medical field is in the minimally invasive surgery. This technology allows the surgeon to make small cuts and provides a virtual feel and look of the patient's internal organs. Detection of cancerous cells from fit cells can also be done using tactile sensing technology. Touch screens use tactile sensing technology. These touch screens can also be used create prosthetics with touch feedback [2].

The development of touch sensing innovation has been foreseen for more than 30 years. Immense possibility and utilization of tactile sensing in ranges of mechanical autonomy was seen by specialist like Harmon [3-5]. As suggested by Harmon, due to technical issues and low rate of profitability, tactile sensing was considered not suitable for agricultural and medical areas of applications [6]. Specialist like Nevins and Whitney contended that the requirement of tactile sensing would be taken out by submissive monitoring [7]. Almost towards 21st century, it was imagined that the innovation can possibly help in the betterment of human beings by helping in the improvement of smart products and frame work [8, 6].Robots for medical field and industrial automation were at the highest priority on the rundown of uses [8].

In areas where other sensors failed to show their significance, tactile sensing gained advantages, for example, vision sensors are not considered as the ideal option in disorganized or scenarios with limitation of space. Even though a lot of significance and exertion has been dropped into the improvement of tactile sensors in the course of recent decades, an agreeable sensor which can deliver feedback similar to the perception of touch in human beings has not yet been acknowledged and thus restricts the development in application areas of robotics and MIS [9-14].

2. Tactile transduction techniques

Some of the usually scrutinized tactile transduction procedures depend on capacitive, piezoresistive, thermoresistive, inductive, piezoelectric, magnetic and optical techniques. The inherent standards connected with these strategies have their own benefits and drawbacks [15, 16]. A possibly prevalent execution and functionality is shown by capacitive, piezoresitive, piezoelectric, inductive and optical types. Thus these are frequently favored option of designers. Concise surveys of these techniques and their benefits and drawbacks have been stated below.

2.1. Capacitive tactile sensors

A capacitive sensor comprises of two conductive plates which are linked by a dielectric material. The capacitance for collateral plate capacitors are given by $C = (A\varepsilon_0\varepsilon_r)/d$ where,

C- Capacitance

A-Covering territory of the two plates

ε_0- Permittivity of free space

ε_r- Relative permittivity of dielectric material

d- Separation of the plates from each other.

Capacitive tactile sensors by and large show a decent recurrence reaction, high spatial determination and have a vast element range. The limitations possessed by these sensors are that they are more vulnerable to clamor, association of field and bordering capacitance. Furthermore, they require moderately complex gadgets to sift through this commotion [1, 2, 17].

2.2. Piezoresistive tactile sensors

The main principle behind these sensors is that, when a force is applied on the pressure sensitive element, the resistance changes. The voltage if a resistive element can be given as $V = IR$ where,

V – Voltage

I - current

R – Electrical resistance of the material.

Normally the voltage or current is kept stable and the variation in resistance is seen by the variation in current or voltage. A pressure sensitive elastomer, conductive rubber or conductive ink forms the resistive element. As the alteration in resistance can be effortlessly measured and are also easy to manufacture and coordinate, these sensors require fewer hardware [1]. These are not easily influenced by commotion and hence function admirably in cross section arrangements as there are not much of field collaborations or cross talk. As compared to capacitive tactile sensors, resistive tactile sensors experience the ill effects of hysteresis and in this manner have a lower recurrence reaction [18, 19].

2.3. Piezoelectric tactile sensors

When the gem cross section in certain precious stones and in fewer earthenware products is distorted, a voltage potential is created [20, 21]. The property which allows the gem to recognize horizontal, vertical and shear forces is the reactivity of the gem which depends on its shape. The graph plotted between voltage created and the force applied or pressure will be a linear line i.e., the force applied or pressure is directly proportional to the voltage V. these sensors are the perfect option for calculating vibrations as they display an extremely great high recurrence reaction. But due to their vast inner resistance, these sensors cannot calculate static forces and are suitable only for active forces. The inner impedance and the constant of dielectric of the piezoelectric layer, controls the time constant. The input impedance of the gadget plays an important role as it influences the response of the gadget and is hence taken into consideration during the designing of the sensor.

2.4. Inductive tactile sensors

The secondary coil senses the magnetic field which is induced by the primary coil. The secondary coil regulates the magnitude and phase of the measured voltage by regulating the common inductance between the coils. The advantages possessed by these sensors are that they have a high active range and an uneven development. The disadvantage is that these sensors are huge in size and this causes a reduction in spatial determination when assembled. They also have lower repeatability due to the mechanical functioning as the coil does not return to their original place. For the primary coil, an alternating current is required, hence delivering a yield voltage at the same recurrence. Since the magnitude of the alternating signal has to be demodulated, these sensors require complicated electronics as compared to the resistive based tactile sensors [22-25].

2.5. Opto-electric tactile sensors

The three most important components of these sensors are:

- A light source,
- Transduction intermediate and
- A photo detector that is mostly employed as a camera or a photodiode.

Typically transduction takes place when there is a variation in the tactile medium. This variation adjusts the transference or reflectance strength or the range of the light source as the force applied differs. The most important advantage of these sensors are that they have elevated spatial determination and are resistant to normal lower recurrence electromagnetic intrusion produced by electrical structure. The major disadvantages are the size of the sensor and its unbending nature. Even though they give a far reaching recurrence reaction, they require significant processing power [26-29].

2.6. Strain gauges

These sensors are the most commonly used sensors and are cheap. The variation in resistance is used to calculate the mechanical strain [30]. Based on the needed duration, these gauges are fixed to the substrate by making use of glues specially made for this purpose. Strain gauges are extremely delicate and are profoundly vulnerable to moistness and temperature variations. To avoid these issues, strain gauges are frequently utilized as a part of Wheatstone bridge arrangement. Strain gauges cannot recuperate if overloaded. Since strain gauge is a mechanical device, it has elevated hysteresis and has non-straight reaction. Strain gauges have been broadly utilized for quite a while and are frequently used in many applications which are their major advantage [31, 32].

2.7. Multi-component tactile sensors

Various transduction methods can be integrated into one sensor to surpass the deficiencies [33, 34]. For instance, a PVDF (polyvinylidene) coating measures active forces and slip and cannot measure stable forces. To overcome this, resistive or capacitive components can be used, which helps in the measurement of slip and stable forces more better [33-36]. Applications which require adaptability or huge region scope, liquid dependent tactile sensors can be utilized, consolidating different natural techniques to accomplish the errand.

3. State-of-the-art

As of late, tactile sensors have been under specific consideration because of areas of utilization not precisely identified with robotics. The first one being the ally of human and machines which is shown by the touch screens and is mainly used in correspondence gadgets and PCs [37-39]. Touch screen innovation has been utilized subsequent to 1980-1990s; however it is the recent eras of cell phones that cultivated the exploration in the most recent five years, shown in a substantial amount of patents. The second application area being pharmaceutical, to be specific MIS and distant surgery and treatment and tissue portrayal [40]. Haptic detecting improvements are influenced by the practical reality applications [41]. In any case, and with the special case of the two aforementioned instances, the evolution of tactile and touch sensing has taken place, yet not in a determined path due to many reasons. As compared to vision, tactile sensing does not generate effectively evaluated signals. Thus a great deal of performance is needed with the collection of the most important data. But the major issue is the absence of target and in the details required. The specifications usually differ with the application. But by defining specific general purpose uses, it provides a better foundation for the development of sensors. Many authors have given explanation regarding the requirements of tactile sensors for the application of robotics, but not in a decisive way [42]. When such specifications are absent, the evolution of touch sensing is carried by applications or as a commodity of using MEMS or nanotechnology transduction methods. Micro and nanotechnology use tactile sensing execution, since they can create not just an elevated bulk of sequence of sensors, additionally gadgets joining both of the sensors, necessary molding circuits and signal acquisition equipment and embedded system. Humidity and temperature transducers can also be used in these devices as they enhance the performance of the tactile sensors. Also these are importance as they convey the information acquired by the sensor.

3.1. Mems

A huge dominant part of the tactile sensors created not long ago, uses MEMS innovation. They are principally either polymer with natural material substrate based or silicon based sensors. For the detection of force in polymer based, a piezoresistive rubber is used [43]. Polymer based sensors have lower manufacturing rate per unit area and are thus preferred over silicon based for wide area touch sensors. The disadvantages of polymer based sensors are that they have less spatial determination (around 2mm) and the quantity of taxel because of wiring forms the upper limitation. The usage of organic-FET matrix solutions in [44] is not only advancement but also is reliability for applications. The thickness of natural FET is less as compared to the present technology of silicon. A large amount of writings based on silicon MEMS tactile sensor is presented in [45, 46]. Sensor utilizing silicon micromachining have the benefit of silicon high elasticity, diminished mechanical hysteresis and a reduced thermal coefficient of expansion. A large portion of silicon MEMS tactile sensors are dependent on piezoresistive or capacitive taxels and through the reconciliation of an exchanging framework manufactured utilizing CMOS innovation, the amount of wires can be diminished. The CMOS innovation permits likewise joining of the taxels cluster conditioning circuits. Compared to polymer based sensors, the spatial determination in silicon micro machines tactile sensors is high. But however, it is hard to acknowledge adaptable sensor surface. An answer for these issues is described in [47]. The sensors are coated with polydimethylsiloxane (PDMS) to protect them from mechanical damage. PDMS has qualities like water resistance, artificially latent and non-dangerous silicon based natural polymer provided as a two section blend, a monomer and hardener mixed at weight proportion of 10:1. This is usually utilized for implanting or exemplifying electronic components.

3.2. Nanotechnology

As far as anyone is concerned, a tactile sensor completely built on nanoscience has so far not been delivered. But, there are reports showing usage of nanomaterials [48-50]. Also there are nanomaterials that are used for low compel detecting [51] and also for touch screens [52, 53]. The most intriguing nanomaterials based tactile sensors is accounted for in [54]. A glass backing with anode coating has a 100 nm thick film based on it. The glass backing is topped with 5 layers of gold and cadmium sulfite nanoparticles in an alternating fashion. These layers are isolated from one another by polymer sheets. The gadget is finished off with an anode covered adaptable plastic sheet. When the plastic coating on the sensor is squeezed, the nanoparticle layer turns out to be nearer and electrical current streams. At the point when the electrons skip between the nanoparticle coatings, the cadmium sulfite nanoparticles sparkle and this light can be collected on the opposite side of the glass. The electrical current and light produced as output by the sensors are proportional to the sensor pressure. When the obtained light is recorded with the camera, about 5-10 readings for each second is taken by the nano-film. But with the electrical current the readings rise to above 20-50. This sensor has a horizontal resolution of 40 µm and a vertical resolution of about 5 µm. Whenever the sensor is squeezed against an entity, the film makes a geographical guide of the surface by conveying two signals which are electrical and visual and these are interpreted by a camera. The resolution of space offered by these maps is in the same category as that attained by the human touch. The main aim of this sensor is to enhance the minimally invasive surgery (MIS). However, its future in guiding robots to hold delicate objects is exceptionally appealing even though the sensor cannot determine the pressure direction. It stays to check whether nanoparticle layers can grab this sort of tactile data that is necessary for adroit control of delicate objects.

4. Applications

The various application areas of tactile sensing are briefly discussed below.

4.1. Touch Screen

From the perspective of tactile sensing hardware components the touch screens are fairly basic, man-machining interfacing are equally as compelling as the tactile sensing. The hardware demands a controller which has the ability to process and to run the software that decides the tip to tip connection. Surface acoustic waves sensing are considered to be a standard touch screen monitors [55]. On the monitor glass plate, two of the transducers are set along with the two axes (i.e. x and y) (Figure.1a). Along with that a reflector is also placed on the glass, which reflects the signals which are electrically charged and they are transported from one transducer to the other (Figure. 1b). When an operator places his fingers on the surface of the glass, the fingers consumes a bit of the energy from the waves produced, in the mean time the transducers can spot and detect accordingly.

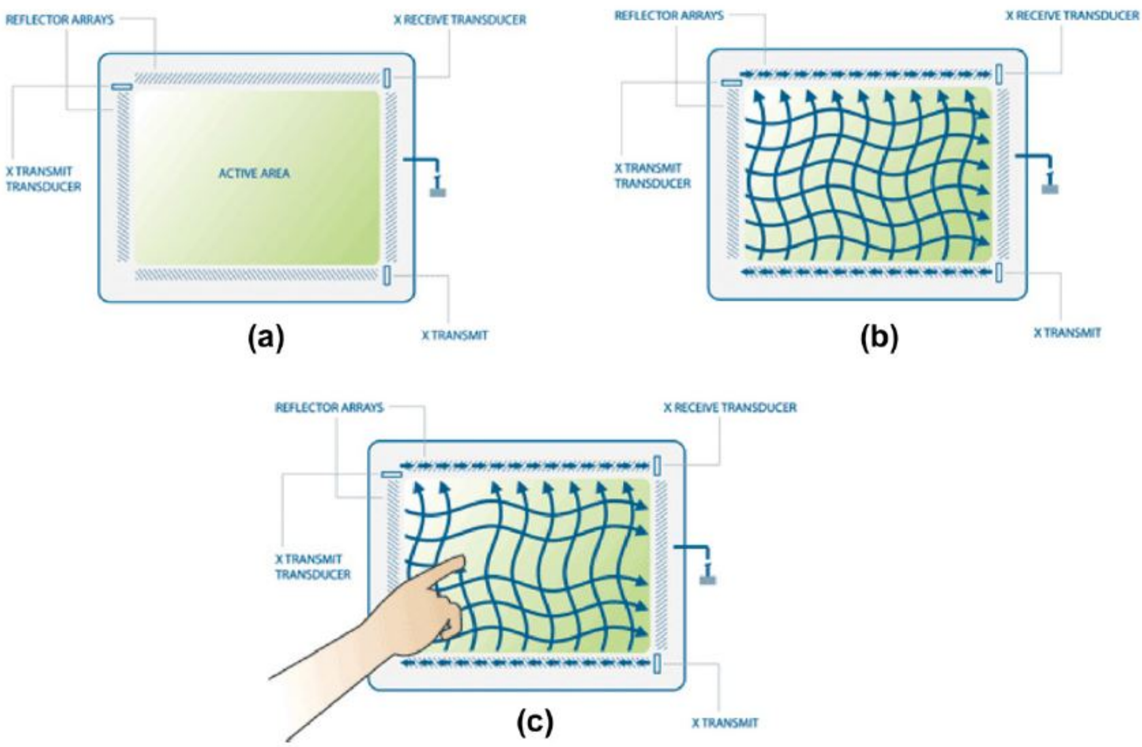

Figure 1: Surface acoustic wave touch screen (a). Constitution (b). Non-disturbed acoustic waves pattern, (c) Acoustic wave pattern when touched [2].

The shutter doesn't have any metallic portion, thereby allowing the light to enter in completely and hence perfect image clarity can be obtained, thereby enhancing this kind of touch screen for projecting specific graphic. Since SAW touch screen are built by glass, make it's long-lasting and can also be operated even when scratched. They also carry some disadvantages which are as follows:

- The movement in liquids or due to condensation, there can be a possibility for false alarm.
- Due to solid infection restricted areas are created.
- Unique design can overrule the vulnerability to misusage.
- The screen must triggered by the fingers, covered hand and stylus with soft tip.

The touch screen are not systematic enough to draw and to drag, and also doesn't support multi-touch. When smart devices are been operated multi-touch is highly efficient, which runs different application like browser, to revolve, the requirement to stretch more than one finger. In-plane- switching techs which are used in Apple iPad and the latest class of iPhone frequent result.

4.2. Agriculture

Like service robotics, the agriculture and food production field is well automated but new technological advantages in tactile sensing are not featured. Tactile sensing has a potential for inevitable development even though its uses are ordinary. High numbers of human operators are required for processing of natural produce. Manufacturing automation cannot handle soft, delicate and highly variable items at low cost. The interest has been increased regarding the possibility in the reduction of human inclusion, in order to avoid disinfection, to get involved in risky ambiance without taking any precautions and to finally get rid of miscalculation done by humans [56].

4.3. Surgical Applications

Resection is been considered to be elevating and quickly growing in the places where touch sensors very vital in today’s world. Minimally invasive surgeries (MIS) are old methods, but they are now practiced for several operations .In spite of its advantages, during manipulation Minimally Invasive Surgery greatly reduces surgeon’s perception. Surgeries are essentially a tactile and a visual occurrence and any deficiency regarding the surgeons sensory skills are take to be undesirable. For example, through a tiny punctured opening the laparoscopy long slender tools have been inserted. In the walls of the abdominal the operator adopts a variety no. of instruments that are pointed and navigate pictures from the video. The instruments used are inflexible rods which have stable pivots at the starting point, the degree of freedom available are confined. This is one of the main difficulties together with absence of 2D view and also complete absence of touch sensing. The prime reason why touch sensing is crucial is because, the delicate tissues can only be checked and recognized by determining its viscosity, fragility and its flexible properties hence this proves that tactile sensors plays a vital role in this area.

For breast cancer an array of touch sensors are used to navigate, instead of a mammogram, regarding ultrasound systems along with other complicated systems. A batch of twelve to sixteen touch sensors are highly fragile than the touch senses of human being and the navigation of lesions as tiny as 5 mm below the surface of our skin are achieved . The probe had about 200 sensors and the system is making use with success [57]. An array of tactile sensors which are of different sizes and configuration has been used for large scale for medical application; some of them are as follows: Minimal Invasive Surgery, orthotic assessment, main frame of diabetic foot prosthesis and brace fitting, advance seating and setting people who are neurologically composed, artificial creation under dental and orthopedic research. Now Minimal Invasive operation are focused more as compared to non-invasive surgery, the reason being is that it has the least negative hit on the inmates another advantage is that it will reduce the stay duration in the hospital and also lowers the cost. Various methods are classified and are essentially invasive. Through the body cavity or through skin, most of them are carried out. Phenomenal break and revert to laparoscopic equipments for an oblique scanning over operational field and to mold instruments that are remotely controlled. Figure 2a presents the economic opportunities where robots provided services to Da Vinci MIS [2]. It mainly contains three segments which are: a mechanism which provides the input (surgeon's console), interfacing (vision system) which are done digitally, and a mechanism (manipulator, patient-side cart) which provides the output. Presently, the primary system doesn't fuse touch as well as the capacity of haptic sensing but various task has been drifted towards that path for both training and surgical purposes (e.g. suture training) [58].Tactile sensor can be also used for gait analysis. Sensors which are established by Tekscan Inc. which provides the balancing in the functions of a foot. While gait if an imbalance is observed in the foot, a torque which is repellent and force segments which creates friction on tissues present on our which causes a sort of uncomfortable sensation .Touch sensing are proposed in dental implants. Tactile Technologies, Inc., ILS comprises of copyright technology that allows attaining the images of maxillary bone contour which are mechanical without clearing out any tissues of the gum. The injection is calculated by using miniature position encoders and a DSP electronic [59].

(a) (b)

Figure 2: (a) Da Vinci surgical system (Courtesy of Intuitive Surgical, Inc.). From left to right: surgeon console, vision system, and patient-side cart; (b) detail of the patient car [2].

4.4. Robotics

Robotics applications use various tactile sensing techniques. The main use of tactile sensing in robotic applications is to furnish the robot's manipulator with the exact information regarding the object it has to hold or handle.

Figure 3 illustrates a robotic hand from Barrett Technologies, Inc [60].

Figure 4 shows the PR2 robot gripper with pressure sensors attached to the robot's fingertip. The fingertip of the robot gripper is equipped with a group of sensors consisting of 22 single cells. On the parallel gripping surface, these sensors are arranged in five by three arrays, with two sensors each on the fingertip and at each sides and one at the back. The perpendicular compressive force which is applied at each of the sensed region is measured by the sensors. For the desired grasping, a layer of silicon rubber is used. This layer is a protective layer covering the sensing surface and provides the acquiescence and the friction necessary for the grasping. This tactile sensing gives the PR2, the ability to pick up and position the object delicately without damaging or dropping the object.

Figure 5 shows the SynTouch Biotactile Sensor. This sensor uses a thermistor, a set of impedance sensing electrodes and a hydrophone to implement temperature, force and vibration sensing respectively. BioTac sensors can execute a task much better as compared to human.

Figure 3: Barrett hand [61].

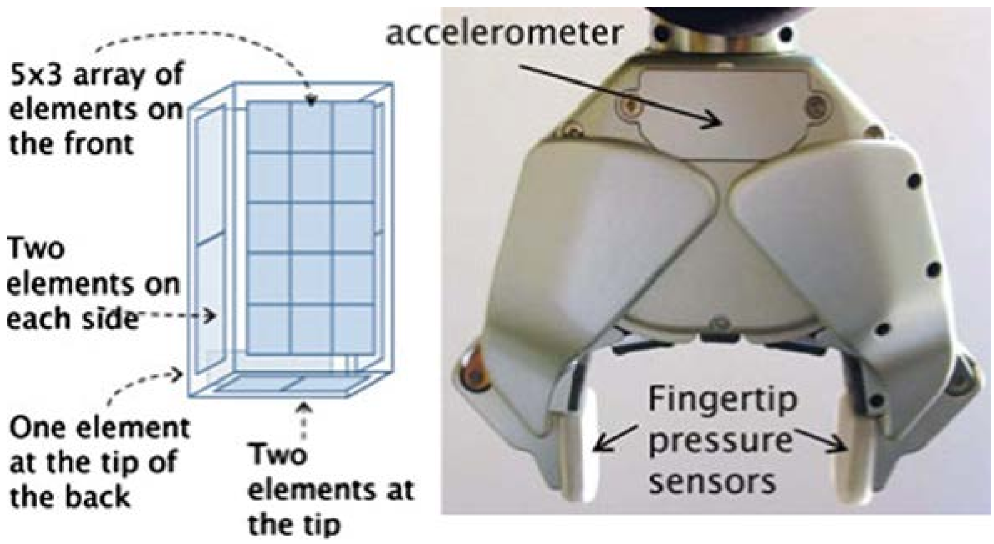

Figure 4: the PR2 robot gripper. The pressure sensors are attached to the robot's fingertips under the silicone rubber coating [2].

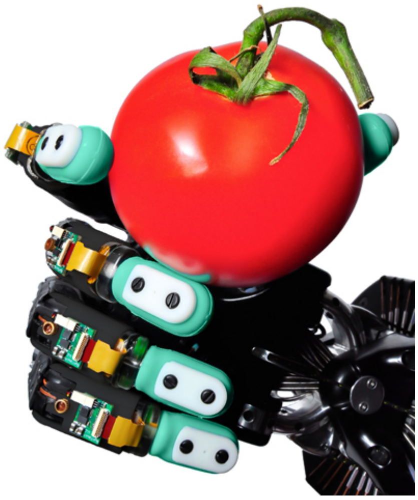

Figure 5: SynTouch BioTac tactile sensor [2].

5. Conclusion

Tactile sensing technology can help in many future applications in various fields. Proposals regarding new areas of applications have been suggested. Over the previous decades, tactile sensing has been evolved into a technology that is advanced. As observed, there is an increase in the demand of tactile sensing technology in various industries. This is revealed by the number of papers published and also the patents filed. The number of publications indicates an increase in the research activities in these areas. In the past few decades, tactile sensing was a failure. But as of now, it is widely accepted and used in many applications. Major area of applications has been seen in mobile devices, which uses tactile touch screen interfaces. Other areas that promise a key role of tactile sensors include medicine, especially in surgery, agricultural and food processing industries. Medicine is one of the future markets for this technology, as there is an increasing need for solutions to assist the surgeon in minimally invasive surgery.

Russell and Nicholls described the fundamental transduction methods and these methods have been developed since 1990s.

Present day researchers are concentrating more on the new packaging, providing better designs, upgrade engineering and also provide a complete analysis. Tactile sensing technology has the ability to help in future development in various application areas as discussed before.

Wireless tactile sensor is one the topics yet to be addressed. The major issue faced by these sensors is the interfacing wires, for example, while connecting on a rotating surface. Optical arrangements as of now have been suggested.

A study conducted at the University of California, shows the option of utilizing RF dependent remote sensors is progressively all the more intriguing. It is accepted that the robots with haptic and touch sensing will have the capacity to advantage from all the task which is being produced in the connection of implanted remote conveyed framework. In not so distant future, the development of remote taxels or intelligent remote assembly of taxel with integration of advanced detecting abilities, for example, temperature can be envisioned.

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