In-depth scrutinization of In- Mold Electronics for Automotive applications

Srinivasan KP* and Muthuramalingam T

Department of Mechatronics Engineering, SRM Institute of Science and Technology, Kattankulathur - 603203, India

*Corresponding author’s e-mail: sp3048@srmist.edu.in

Abstract:

Conductive inks have been extensively researched owing to their popularity in Printed Electronics and Flexible Electronics. IME is one of the most important technological developments of this century. In an effort to summarize the latest advancements created by Injection Molding, Thermoforming and Printed Electronics in the field of In-Mold Electronics, this consolidated report describes the key technologies and challenges in meeting the requirement of Automotive Cockpit Electronics and its specifications, as well as an overview of Touch Capacitive sensors development with a range of conductive inks and techniques.

Keywords: Printed Electronics; In-Mold Electronics; Inkjet printing; Roll-to-Roll; Screen printing; Cockpit Electronics

1. Introduction

The paper explores the capacities of Design and Development for low-volume-to-large printing of capacitive sensors, conductive inks and discusses how these materials can be used to manufacture in-mold Electronics component for Automotive Cockpit Electronics application.

Technology In recent years, the most conventional car industries have experienced slow or decreasing growth, due to emerging technology such as very Clean energy developments [1,2]. There are also concerns that a growing number of young buyers and their increasing procurement capacity would have an impact on certain potential expectations. The business has major challenges to overcome both global growth and the demands of the younger generation.

Owing to the dynamic integration of features such as mechanical buttons, silicone pads, Hard PCBs, encoders, industry engineers continuously search for ways to enhance user interface controls (UI). The usage of touch sensors increases the versatility of an industrial designer by reducing the difficulty and sophistication of traditional specifications. The user can now enjoy it more appealing in intuitive if even with the futuristic appearance of interior [3].

They are a resistive touch sensor that is commonly used extensively in vehicles and few OEMs use an Infrared UI and most OEMs look for a capacitive sensor, owing to its drive and gain on the consumer market. Rigid glass panel and a film divided by a near distance are the Resistive sensors [4,5,6,7]. The two translucent electrodes were mounted on both Glass and film and both attached thru Spacer at Non-Visible area or boundaries, The Pressure creates electrodes on the glass in the film, allowing the
current to flow, where the voltage difference is sensed and the touch point is detected. The most critical market share of these Touch sensors was attributed to the low cost and ease of implementation considering the low reliability and optical efficiency due to electrode arrangements [8,9]. Scanning infrared touch sensors are based on the idea of deciding location by splitting one or more of a set of light beams and thus interrupting the arousal of a beam-lighted phototransistor. The infra-red light is blocked when the touch sensor is touched and does not hit the infra-red imaging sensors. Production costs for this type of sensor are high, and initial calibration is complex and difficult and Environmental light may also influence the output of touch sensor that contributes to false touch [10]. Capacitive sensing is the commonly employed in mobile industry. The touch activity is detected through detection of small electric charge shifts (Spatial Interpolation) between the Electrodes induced by finger touching. Substrates may be glass or flexible polymers for capacitive contact sensors or combinations of both [11]. The sensors are typically designed as conductive strips. One of the most broadly applied sensor architectures is inter-digital electrodes. The Electric charge shift induced by a close proximity of a finger or a conducting object or stylus close to a junction is 1 pF or less and may have less than 0.1 pF on an adjacent electrode [12]. Analysis of capacitance changes at or around electrode crossings shows touch effects if capacitance values exceed the threshold value fixed in the system. Capacitive sensors are highly resilient and most contaminations are not impaired [13]. These benefits have become particularly desirable for the implementation of versatile electronics in the next decade. Multi-touch technology is familiar to virtually any device and is used efficiently with many devices, for example mobile phones or notebooks. Tasks, such as authentication of corporate mails, personal details or simple touchscreen usage of the computer.

2. User Experience

The touch sensor is indented for touch sensing (one or Multiple), the electrodes can be attached for one or many touches to a single capacitive sensor. The important influence for number of fingers used as INPUT gestures has been observed based on the participant survey. The produced gestures were system size independent. The percentages of gestures in each category compared, computed, concluded by using ANOVA method [14]. Concluded that the Maximum number of inputs given to device is by using One Finger and some of finger gestures as shown in the Figure 1.

3. Block Diagram of Touch working principle

The Figure 2 of the General block demonstrates outstanding computer systems of one touch or multi touch. Computing may involve one or more processors, Random access memory peripherals, Watchdog timers, etc. The sub structure consists of sensory pathways, logic of search, logic of driver. The scan logic for a channel will reach the RAM and interpret sensory data and monitor sensory
channels. Channel Scan Logic can additionally monitor driver logic for producing stimulus signals at different frequencies and phases [15,16]. Electrode is a touch sensor in which Tx (Transmitter) and Rx (Receiver) have been developed on a requisite basis. A capacitive sensing node can be considered as a picture unit (Pixel) at each intersection of Tx and Rx lines, which is especially useful when viewed by a touch sensor to catch an image. Once the subsystem has sensed if a tactile incident in each node of the touch sensor has occurred, the touch sensor pattern in a multi-touch panel may be viewed as a touch image. The infotainment system can also include host processor for receiving outputs from panel processor and performing actions based on the outputs that can include adjusting control settings, opening a file or document, viewing a menu, making a selection, executing instructions, operating a peripheral device coupled to the host device, answer/receive/hold/terminate the phone call, Volume settings. Note that one or more of the functions described above can be performed by firmware stored in memory and executed by processor, and functions are executed by host processor [17,18].

4. Infotainment structure

In automotive Infotainment control panels, display device with touch sensor panel are fixed thru OCA or LOCA or Air gap arrangement as shown in the Figure3a,b depends on Product quality, Segments, customer requirements. The display is located partially or entirely under the touch sensor panel, can form touch screen. Liquid optically Clear adhesive (LOCA) is liquid-based bonding Technology increases the contrast ratio by reducing the volume of reflecting light and therefore improves visibility [19,20,21]. This is extremely relevant in outdoor applications where direct sunlight can limit visibility. The LOCA/OCA layer between the Display and Touch sensor panel enhances the resilience of each part from effects. The structure's LOCA/OCA layer acts as a shock absorber. When utilising layers of a glass substrate-based Touch sensor, the effect is even greater. For an air distance, the Touch sensor based on the glass substrate will deflect enough to create a crack in the glass. The LOCA/OCA layer stops the sensor glass from flexing enough to fracture. In-Mold Electronics Infotainment with LOCA would boost shock tolerance unmatched as Plastic Resin will not crack very easily but there is not sufficiently analysis and data-based inference present.

5. Photolithography

The conventional approach to capacitive sensor manufacture includes a rather complicated manufacturing technique, whereas the ITO-based capacitive sensor on the rigid glass substrate has many disadvantages due to its deposition, which entails expensive methods of vacuum deposition such as sputtering and even complex post-patterning processes such as photolithography and chemical etching [22]. These processes can be replicated in order to manufacture the finished component with each layer of the sensor, additionally it is costly and its use is restricted due to the list of brittleness, high material cost and comparatively low conductivity. Following the performance of the
A semiconductor and flexible sensor is anticipated to become the next market wave. Rapid integration capability may be utilised to build innovative technologies and software. After their conception more than a century ago, Printed Electronics has gone a long way. Today, the term encompasses the whole sector devoted to the production of electronics equipment and systems that incorporate this technology. Comprehensive creation of non-conventional electronics such as flexible sensors, touch displays, smart labels, solar cells, digital posters, wearable devices, etc. are areas of development by Printed Electronics.

6. In-Mold Decoration or Labeling (IMD/IML)

It is also referred to as film moulding. It is used to decorate components and has many uses in vehicle interior parts, home appliance control panels, pots, cups and assorted vessels, etc. This technique is used to decorate the plastic component with such a film or label throughout the injection process. The label or film becomes an essential element of the finished item or substance that produces a slightly different appearance of the object. In this process, the pre-printed label or decorative film or functional film shall be mechanically, electrostatically, by gravity or Vacuum put in the open Plastic Injection Mold and retained in place [23]. When the mould is closed, the plastic resin is inserted into the film and permanently encapsulates the film in the finished component. In-Mold Electronics (IME) blends IMD and Printed Electronics. Moreover, the introduction of Printed Electronics into in-mold decoration (IMD) is one of the most important technical innovations of this century owing to its massive advantages such as Light Weight, Thinner, Non-Breakable, Free Form factor, Low cost and ease of processing and ease of integration [24].

7. Electrode configuration for the capacitive sensor

There are two forms of architecture focused on the calculation of current and its production sophistication however the Sensor Pattern type and design should ensure the electric charge (Spatial Interpolation Figure 4a.) is uniform and no abrupt discontinuities. The Self and mutual capacitance are commonly utilised on the basis of a requirement. Self-capacitance is a basic construction of nature where each electrode connected to the ground and easy to manufacture, but is restricted to a single touch and a double touch, however there can be a ghost touch (False Touch Detection) where, as in Mutual Capacitance, the deliberate or unintended capacitance between two “charge carrying Electrodes” named Node may be handled or sensed by the device. The Diamond pattern is more widely used in electrode design owing to its benefits of minimum impedance and increased optical efficiency due to the uniform propagation of light across electrodes. Few sensor pattern configurations are illustrated in Figure 4 b, 4c, 4d.

8. Conductive Ink materials

The automobile sector is becoming a significant growth area for leading ink manufactures. The windshield detergents, seatbelt buttons, airbag deployers, seat occupancy indicators and heaters have been served over several years by Printed Electronics. Many researches include touch screens,
translucent heaters in mold electronics is in progress and this has made engagement with automotive OEMs/value chain a high priority imperative [25]

In the print electronics Industry, conductive inks are typically used for the development of printed circuits. Conductive inks are focused on complex combinations of different materials. The conductive component, which can be based on metal or carbon particles. The Resins are used to spread and preserve the mechanical and elastic properties of conductive particles. Solvents are used to extract resins and to control the rheological properties of the pigment, and chemicals are used to modify the processability or functional properties of the pigment.

8.1 Selection criteria

Electronic charge properties are essential items for printed material. Printability depends on the nature of the ink, the material, the distribution of the scale of the particle, the shape of the conductive filler and the surface tension on the substrate. The properties of the material, such as permeability, surface roughness, porosity or surface energy, also influence the quality of the printed structures in addition to the printing conditions, including the drying/curing process. Electrode materials are a central element impacting both the concept and the manufacturing phase. The electrode material must not only provide optimum efficiency, but must also provide the required durability for efficient operation in the expected environment and cost-effective production, so that the choice of conductive ink is important and the requirements are arranged into parameters such as optical, electrical, chemical and mechanical.

8.1.1 Optical

Proper materials must be "clear" enough not to block or negatively impact the view of the display. Transmittance, Haze, and Tint are also optical factors. The values of Visible Light Transmittance (VLT) range from 0 percent (opaque) to 100 percent (transparent). A acceptable VLT level is usually 85 percent VLT or higher for several applications in the touch screen industry. Haze is induced by the absorption of light within the electrode layers, and the presence of haze on the touch screen is caused by a cloudy/murky look. As such, in the case of haze, engineers and designers typically pursue a limit of 3% or less. The unwanted colour casting from the panel is caused by the tint. In order to ensure that it does not create an excessive hue that would adversely affect the design, it should be noted the inherent colour characteristics of the electrode materials.

8.1.2 Electrical

The electrical output of the capacitive touch sensor may be dependent on the resistance of the material used. The resistance is calculated by the sheet resistance of the material and, in general, the lower the resistance of the material, the simpler it is to improve each electrode for capacitive touch sensors, since this provides better response time to the rest of the circuit. The sheet resistance is measured in ohms/square.

8.2 Mechanical

The mechanical characteristics of the electrode material should be compatible with the mechanical characteristics of the finished component. For eg, whether the end product is bent or moulded, there may also be properties of the electrode material that allow it to be bent or created. More specifically, this tends to be essential in the case of in-mould electronics, where the lightweight printed circuit is thermoformed and/or moulded to the required specification. During the process, the formation of the material induces bending and stretching in the electrode. Electrode materials would need to be sufficiently robust during processing to survive temperature and pressure.
8.2.1 Environmental durability

It ensures that the material should be able to tolerate temperature, humidity and UV ranges in order to minimise breakage or consistency issues. Any of the OEM test specification is combination of temperature and humidity evaluations. Thermal tests will vary from -40 °C to 90 °C, the humidity varies from 50 percent to 95 percent RH and the temperature shock shift from -40 °C to 90 °C within 10 sec.

8.3 Ink Materials

A variety of different materials, including metal nanoparticles, conductive polymers, carbon materials and organic/metallic substances, may be used for the preparation of conductive ink. Metal nanoparticles and carbon materials are today the most commercially available conductive inks.

The following Transparent conductive materials involve, but are not limited to, Silver nanowire, Copper ink, PEDOT carbon nanotube and ITO for automotive applications [26].

Silver NW: One of the translucent conductor materials from several conductive ink manufacturers is used for touch sensors. Comparison of the resistance and transmission of silver nanowires by gravure and spin coating process as seen in Figure 5a. It suggests that high transmission leads vice versa to high resistance, but Haze is also lower when high resistance is present. It is necessary to trade off Optimum Haze and transmission based on other elements such as cost and availability. The Figure 5b shows that the rise in the bending radius contributes to an increase in resistance, so that the bending radius plays a key role in the nature of the device [7,27].

Carbon nanotubes (CNTs) are a promising material for flexible electronics, owing to their strong mobility, conductivity, Transparency and mechanical versatility. CNT diameter varies from around one nm to several hundred and the length ranges from a few micrometres to 2 millimetres and the wall ranges from single-walled (SWCNT) to multi-walled (MWCNT) and the length-to-diameter ratio may be as high as 132,000,000:1. The above parameters are special in nature as compare to other conductive materials. It is noted from that resistance rises negligibly in CNT as compared to other materials where resistance increases multifold [28].

![Figure 5a. Transmittance and Haze change](image1)

![Figure 5b. Silver Ag bending test](image2)

9. In-Mold electronics

In-Mold electronics incorporates decorative film from the IMD process and combines it with functional electronics. This is done by printing conductive silver inks on thin plastic film. In-mold decoration (IMD/IML) also known as film insert molding. IML applies to the In-Mold Label, which is a similar IMD procedure used mainly to decorate pots, cups and varietal vessels. The strategy is to decorate the injection molded component with a decorated film during the injection process. The label becomes an important part of the finished product, making a completely painted object on the visual surface or partly as a label on a jar. In this method, a pre-printed label or decorated film is placed into an open plastic injection mould and kept in place mechanically, electrostatically, by gravity or by vacuum. When the mould is closed, the plastic resin is inserted into the film and permanently encapsulated within the finished component. The basic method is demonstrated in the form of a flow
chart in Figure 6. The IMD process essentially comprises of 3 steps, 1. Printing, 2. Forming, 3 injections of resin and the IML skips the forming process and the series of production skips the analysis and the analysis stage shall be used to prove out the product design before series production.

![IMD Basic Process Flow Diagram](image)

**Figure 6. IMD Basic Process Flow Diagram**

### 9.1 Screen printing

It has long been viewed as one of the easiest ways of printing images onto something without the need for very substantial raise in the prices. Printing has moved well past screen-printed graphics. There are tonnes of industrial substrates that are widely viable for a variety of various applications. Roll-to-roll coating is also suggested as an economical solution for processing lightweight printed electronics as it offers faster line speeds and allows for continuous output. Manufacturers already produced sensors with good yields and costs that are extremely favorable. Choosing the correct coating method is critical to having the best performance, the various coating processes used in the manufacture of printed electronics, including gravure, slot, and slide coating [29].

Another essential feature of IMD is the selection of substrate materials. PA films, also classified as acid-free, have exceptional chemical tolerance, strong clarity, decent technical resilience and high temperature deflection. PC (Polycarbonate) film has good optical properties, is thermoformable, durable and heat tolerant. Polycarbonate is an amorphous substance that is short in tolerance to chemical attacks. Acrylonitrile butadiene styrene (ABS) has a rather high impact intensity and it is also transparent, giving a good price-performance ratio. Polypropylene has a superb efficiency ratio and remarkable chemical tolerance. They are seen more commonly in identification markings on containers. PMMA provides outstanding tolerance to scratching as it is treated with paint or clearcoat. It is particularly ideal for multi-dimensional optical devices, relative to alternatives. Polyester has good thermal stability, good strength, good dimensional stability and clearness of transmittance. These films are used in many industrial items, including washing and household products [30].

### 9.2 Thermoforming

Thermoforming method is a further advancement for IMD. The film must be chosen based on application, product cost, and accuracy. The printed film is then normally generated for the IMD method and is grouped together as Vacuum, Pressure and Matched Die. The formation method should be chosen on the basis of the application, Product cost, Accuracy. In certain situations in automotive applications, Pressure Thermal Forming has a good benefit of being restricted to a uniform wall
thickness as compared to other formation techniques. The printed sheet is heated and then pulled into a female mould by evacuating the air from it. And the printed film takes the form of the mould. The forming phase produces a stretch in the content that can contribute to deformed or misplaced graphics. To understand the amount of stretch the film undergoes, a mark printed with a grid pattern is processed. Variations in the grid pattern after processing can be clearly seen. This helps the graphic artist to change the graphics that may be influenced by the stretch. The drawing ratio is the secret to knowing thermoforming processes. The component has a limited surface area that requires to be protected by a flat two-dimensional layer. As the sheet is heated and pushed over or into a mould, it must be bent to adhere to the design. It thins out as the sheet spreads. Local design features on the part can render the sheet thinner at a higher rate than in neighbouring areas [31,32]. The drawing ratios may be determined as the surface area of the component formed to the footprint of the part. It is commonly accepted that the thermoforming mechanism is at its strongest when the drawing depth ratio is less than 1 to 1.

### 9.3 Placement of film

Another significant aspect is the location of the film in the mould. Vacuum, static charge, the mechanical positioning method in the mould and the mechanical positioning method in the component or the mixture of these methods are potential methods for the positioning of the film sensor in the OPEN mould.

**Vacuum:** Tiny holes in the face of the mould are used to draw a vacuum that helps the sensor to be attached to the mould until it is filled. While this method simplifies loading, there is a risk of dimpling the "A" surface. Due to hard tooling, the design and production of vacuum-hole moulds will increase costs and difficulty if some improvement is required. If the moulding process is done without a sensor film, the resin can cover the holes. Static loading procedure simplifies the design of the mould and decreases the chance of dimpling. The conductive ink should be opposite to the charging side. The thickness, weight, shape and touch area of the film are influenced by the static properties resulting in the precision of the film positioning in the mould. Mechanical Placing Hole and Dwell pin engagement or Protrusion in the part and Cavity in the mould or vice versa.

**Trimming –** The component formed must be trimmed, either before placement into the mould or after injection. The trimming may be performed with either the Blade tool or the Match Plate tool. The matched die method would have a very precise part trim. The Match Plate can be paired with the Injection Mold layout itself for industrial manufacturing and Industry 4.0 for complete automation. The process area should be clean room to prevent debris on the film or in the mold that creates a substantial loss of yield.

### 9.4 Injection Molding

Plastics injection molding accounts for the largest segment of the plastics industry, which is the most widespread method used to manufacture plastic components. Plastic injection molding is a rapid process which produces large numbers of the same products in a short period of time. The range of products is gradually widening and is also incorporating metals composites. High-performance plastics are used in lieu of metals that are typically used in producing plastics. The simple production technique of injection molding in which plastic is heated and then injected into a mold under high pressure. The substance is cooled to solidify, and then the two sections of the mold are opened to release the material. The Component design is an essential factor which has to be integrated into the design. The component is based on the project necessity and the mold is designed by the toolmaker and the tools are produced by the toolmakers. The machine selection is focused on a Part form, Design and Weight. The manufacturing method is the technology used to create complicated three-
dimensional constructs. From micron-sized wheels, micron-sized needles. Industrial 4.0 is the advancement of quality control in production. Injection molding process regulation has three main areas: process parameters, in-mold parameters, and quality management of various types of components. Newer equipment and technologies are being developed to assist with project control. Many developments involve microchips and other sensors that enable the tool itself to understand. Thus, in-mold process control is important.

10. Additive Manufacturing

In a competitive world, as in the car sector, there is often complexity in the expense and quality of the component, therefore the new invention is a factor in production to decrease vehicle costs, two techniques have historically been used, one of which is New design and Modification. New research calls for the development of new products and/or innovations to minimise spending on the initiative. In the near term, this preliminary manufacturing phase is likely to result in higher prices, but ultimately it will be more cost efficient. The Modification Method requires the use of readily accessible parts and products, well-defined procedures and equipment By bringing existing innovations and applying them to a new market, all production costs and manufacturing costs can be lowered substantially. Advantages of additive technology are actively being discussed in manufacturing. Recently known as 3-D printing. It is an additive manufacturing technology that delivers cost-effective, lightweight designs and provides a streamlined process with limited effort. Adoption of AM has been strongest in industries where its higher manufacturing costs are outweighed by the added benefit AM can generate the increased product functionality, higher production performance, greater customization, shorter time to market. The components are made by applying progressively thin or thicker layers of material, whether the material is plastic, concrete, or glass. Popular in AM innovations are computing tools, computer assisted technology, machine equipment, and structured materials. Once a CAD drawing is made, the AM equipment reads the CAD drawing and lays down a layer of Conductive material on the sheet material to fabricate a Sensor component [33,34].

11. Conclusion:

The various ways and criteria for the selection of inks, substrates and manufacturing methods for automotive infotainment applications are analyzed in this report. Owing to the high production of innovative materials and conventional production processes, printed electronics have also gained greater interest. The increased number of research papers and the presentation of Printed Electronics in a range of applications reflect the growing enthusiasm of researchers in their quest to fulfill the promise of large-scale electronics on flexible substrates by cost-effective printing technologies. This paper investigated various developments in the use of human-machine interfaces (HMI) in the development of vehicle cockpits to improve the driving experience and appearance. To help low-volume projects, standalone printing methods are used in laboratories to represent printed electronics and circuits. These printing technologies must be scaled up or combined on R2R production lines without losing the process chemical, physical, or electrical characteristics to allow high-volume growth (Demand/Supply Management) in the automotive industry. Automotive Infotainment with IME bezel can be made to have a durable, waterproof, Free form, Light weight with a high degree of futuristic design, such as Pillar-to-Pillar cockpit, using cost-effective R2R production lines, High Tonnage Injection Molding with High Automation to meet the High-Quality requirements of Automotive applications.

12. References
1. T. Muthuramalingam, M.M. Rabik, D. Saravanakumar, K. Jaswanth (2018). Sensor integration based approach for automatic fork lift trucks. IEEE Sensors. 18(2), 736-740. Available: https://ieeexplore.ieee.org/abstract/document/8119939

2. M.M. Rabik, T. Muthuramalingam. (2018). Tracking and locking system for shooter with sensory noise cancellation. IEEE Sensors. 18(2), 732-735. Available: https://ieeexplore.ieee.org/document/8103766.

3. Youngbo Suh, Thomas K. Ferris. (2018). On-Road Evaluation of In-vehicle Interface Characteristics and Their Effects on Performance of Visual Detection on the Road and Manual Entry. Human Factors and Ergonomics Society. Vol. 61, No. 1. Available: https://doi.org/10.1177/0018720818790841.

4. S. Khan, L. Lorenzelli, R.S. Dahiya. (2015). Technologies for Printing Sensors and Electronics Over Large Flexible Substrates: A Review. IEEE Sensors. 15(6), 3164 - 3185. Available: https://ieeexplore.ieee.org/document/8119939.

5. M. A. M. Leenen, V. Arning, H. Thiern, J. Steiger. R. Anselmann. (2009). Printable electronics: Flexibility for the future. Phys. Status. Solidi. A. 206(4) 588-597. Available: https://doi.org/10.1002/pssa.200824428.

6. A. Dobie. (2019). Flexible PET Substrate for High-Definition Printing of Polymer Thick-Film Conductive Pastes. J. Microelectron. Electron. Packag. 16(2), 103-116. Available: https://doi.org/10.4071/imaps.788036.

7. Venkata Krishna Rao R., Venkata Abhinav K., Karthik P. S. and Surya Prakash Singh (2015). Conductive silver inks and their applications in printed and flexible electronics. The Royal Society of Chemistry, Available: https://doi.org/10.1039/c5ra12013f.

8. Almudena Rivadeneyra and Juan Antonio López-Villanueva (2020). Recent Advances in Printed Capacitive Sensors. Micromachines 2020, 11, 367; Available: https://doi.org/10.3390/mi11040367.

9. Haifeng Ji, Huajun Li, Zhiyao Huang, Baolian Pan, Haiqing Li. (2014). Measurement of Gas-Liquid Two-Phase Flow in Micro-Pipes by a Capacitance Sensor. Sensors 14(12), 22431-22446. Available: https://doi.org/10.3390/s141222431.

10. Geoff Walker. (2018). A review of technologies for sensing contact location on the surface of a display for Information Display. Available: https://doi.org/10.1002/jsid.100.

11. Harshit Sharma. (2017). A Review Paper on Touch Screen International Journal of Engineering Research & Technology (IJERT) Volume 5, Issue 23 Available: ISSN: 2278-0181IJECTONV5ISS23024.

12. M. H. Lee, R. Nicholls. (1998). Tactile sensing for mechatronics—a state of the art survey. Mechatronics 8 Available: https://doi.org/10.1016/S0927-0457(98)00045-2.

13. Janglin Chen, Wayne Cranton, Fihn. (2012). Handbook of Visual Display Technology. Springer, New York.

14. Sabrina S. Billinghamurst, Kim-Phuong L. Vu. (2015). Computers in Human Behavior. Elsevier Volume 53, Pages 71-81. Available: https://doi.org/10.1016/j.chb.2015.06.012.

15. "Chang-Ju Lee, Jong Kang Park, Canxing Piao, Han-Eol Seo, Jachyuk Choi, and Jung-Hoon Chun. (2015). Mutual Capacitive Sensing Touch Screen Controller for Ultrathin Display with Extended Signal Passband Using Negative Capacitance. Sensors 18, 3637 Available: https://doi.org/10.3390/s18113637.

16. Bo Liu (2016). On-chip touch sensor readout circuit using passive sigma-delta modulator capacitance-to-digital converter. Thesis.

17. Alwin Bakkenes. (2019). Android Automotive Transforms Vehicle Infotainment. Aptive, White Paper.

18. Anshul Saxena (2018). Everything You Need to Know About In-Vehicle Infotainment Systems. Automotive, Article. elfochips.

19. Myung Jin Yim, Chang-Kyu Chung, Kyung-Wook Paik (2007). Effect of Conductive Particle Properties on the Reliability of Anisotropic Conductive Film for Chip-on-Glass Applications IEEE Transactions on Electronics Packaging Manufacturing 30(4):306 - 312 Available:...
20. Silvia Cruz, André Sousa, Julio C. VianaJulio C, VianaTiago Martins. (2017). Analysis of the bonding process and materials optimization for mitigating the Yellow Border defect on optically bonded automotive display panels. Displays. Available: https://doi.org/10.1016/j.displa.2017.02.003

21. Jeff Blake and Richard Paynton. (2010). Careful selection of optimal coatings and substrates can result in greatly enhanced display performance. Donotech, Inc, White Paper

22. Sung Ho Lee, Ji Hoon Lee, Cheolwoo Park and Moon Kyu Kwak. (2016). Roll-type photolithography for continuous fabrication of narrow bus wiresJournal of Micromechanics and Microengineering, Volume 26, Number 11 Available: https://doi.org/10.1088/0960-1317/26/11/115008

23. Yao Gong, Kyoung Je Cha & Jang Min Park. (2020). Deformation characteristics and resistance distribution in thermoforming of printed electrical circuits for in-mold electronics application. The International Journal of Advanced Manufacturing Technology 108:749–758 Available: https://doi.org/10.1007/s00170-020-05377-9

24. Clare Goldsberry. (2020). In-Mold Electronics Market Will Exceed $1.11 Billion by 2029. Plastictoday

25. Raghu Das (2019). In Mold Electronics Market. Idtechex

26. Paul Weindorf, Kong Lor, Soeren Lichtenberg, Steven Ponsock (2015). Touch Sensor Transparent Conductor Optical Comparison. Visteon Corporation

27. "Shih-Hao Tseng, Shih-Hsing Hung, Keh-Long Hwu and Chih-Jen Hu, Wei-Ming Huang (2012). Transparent Silver Nanowire Film as Pixel Electrode for Flexible Electrophoretic Display. SID DIGEST

28. Chandrakant Bhat, David P. Brown, Clement Chen (2015). Curved Mobile Phone Cover with Carbon NanoBud TouchSID DIGEST Available: https://doi.org/10.1016/j.compositesb.2018.02.012

29. Joerg Puetz, Sabine Heusing, Marcos de Haro Moro, C. Mikael Ahlstedt, Michel A. Aegerter (2005). Gravure Printing of Transparent Conducting ITO Coatings for Display Applications. Advances in Optical Thin Films. Vol. 5963, 59631E.

30. W. A. MacdonaldM. K. LooneyD. A. MacKerron. (2005). Latest Advances in Substrates for Flexible Electronics. Journal of the Society for Information Display. Available: https://doi.org/10.1889/1.2825093

31. Sencer Karabey,Olcay Ekşi, Ertugrul Selcuk Erdogan. (2017). An Experimental Study on Wall Thickness Distribution in ThermoformingAdvances in Science and Technology11(3):139-142 Available: https://doi.org/10.1889/1.2825093

32. Yao-Wen Chang &Jung-Ho Cheng (2011). Numerical and experimental investigation of polycarbonate vacuum-forming process. Journal of the Chinese Institute of Engineers Available: https://doi.org/10.12913/22998624/71148

33. Tuan D. Ngo, Alireza Kashani, Gabriele Imbalzano, Kate T. Q. Nguyen and David Hui (2018). Additive manufacturing (3D printing): A review of materials, methods, applications and challengesComposites Available: https://doi.org/10.1016/j.compositesb.2018.02.012

34. Hantang Qin,Yi Cai,Jingyan Dong,Yuan-Shin Lee. (2017). Direct Printing of Capacitive Touch Sensors on Flexible Substrates by Additive E-Jet Printing With Silver NanoinksJournal of Manufacturing Science and Engineering Available: https://doi.org/10.1115/1.4034663