CHAPTER 1

INTRODUCTION

1.1 PRINTED ELECTRONICS

Electronic devices have been produced for more than 60 years using a sophisticated method that combines chemical and photolithographic techniques. These methods have been instrumental in creating intricate electronic circuits primarily on silicon or semiconductor materials. However, a paradigm shift in electronics manufacturing has emerged with the advent of Printed Electronics (PE) technology. Unlike traditional methods, using conventional graphic arts printing procedures, PE forms conductive traces on a substrate that is usually flexible and organic to construct a variety of electronics devices. PE technology makes it possible to use a variety of printing procedures to deposit different kinds of materials in a broad range of areas. Producing cutting-edge electronic products is the main objective. Beyond the realms of printing and electronics, PE is a multidisciplinary domain, merging material science, chemistry, physics, reliability engineering, and wireless communication (Suganuma,2014). According to Wu (2017), PE is one of the most rapidly developing technologies nowadays. The ability to build large-scale flexible electronic devices using PE technology has recently drawn the interest of several researchers in both fundamental and practical research. The sector as a whole will have a market value of about $7.6 billion by 2027, and that value is projected to increase over the next ten years, predicts the IDTechEx study 2019-2029.

PE has gained a lot of interest and is now regarded as a significant technique for the patterned application of functional inks to produce flexible, large-area electronic devices. It realizes the patterning of electronic circuits, electrodes, tracks, and devices using the printing concept. The water/oil is primarily responsible for the electrical functioning.

Inks made of soluble inorganic or organic compounds are often made of inorganic-organic composite materials. PE has the advantages of thinness, flexibility, and cheap cost, enabling both high-speed and mass manufacturing. To upgrade and revolutionize both the printing industry and the current microelectronics production sector, PE technology is adopted as the development direction. Figure 1.1 illustrates the key components of PE, which consist of a substrate, an ink, a printing method, and a sintering procedure to produce a printed gadget.

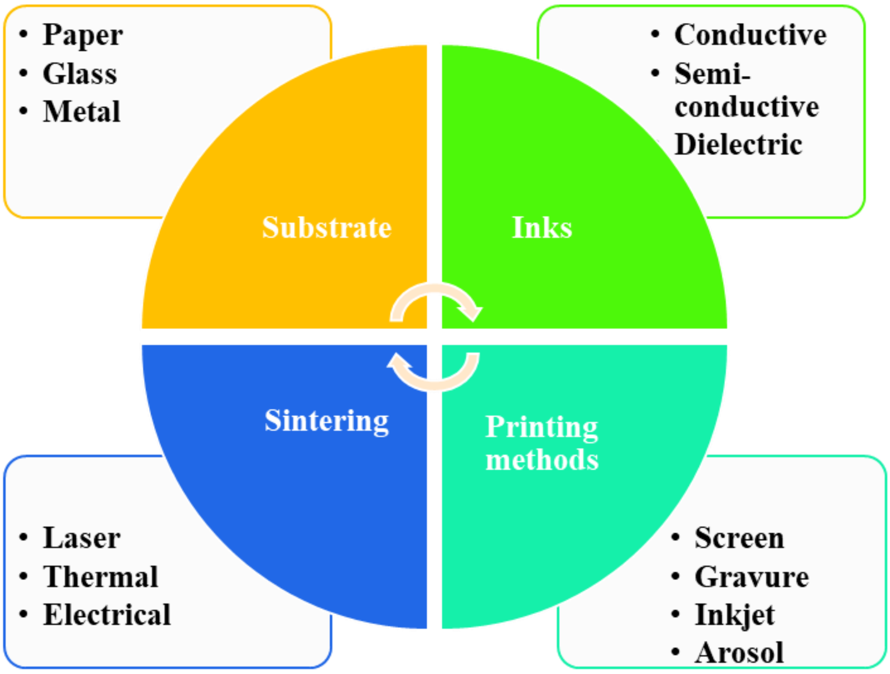

Figure 1.1 Components of PE

The substrate provides the structural support and defines the physical characteristics of the device. This can include flexible materials such as plastics, paper, or textiles, as well as rigid substrates like glass or metals. The ink contains functional materials and determines the electrical properties and functionality. The ink is accurately deposited onto the substrate using printing techniques to create the desired electronic elements, such as conductive traces, transistors, sensors, or capacitors. Diverse kinds of inks can be used such as conductive, semi conductive, and dielectric. The choice of ink determines the electrical properties and functionality of the printed device. The printing technique enables precise deposition of ink into the substrate in desired patterns. PE allows for the use of a variety of printing methods, including flexography, gravure, screen printing (SP), inkjet printing, and others. Regarding the resolution, speed, scalability, and suitability for various substrates and inks, each method has certain benefits of its own. The printed electronic device's performance and dependability are improved by the sintering process, which guarantees adequate bonding and conductivity.

The advantages of PE are given below:

- PE use lower resource usage
- It offers higher throughput
- PE helps to mitigates the use of biohazardous materials
- It enables the production of High-quality electronic components
- PR processes are cost-effective and
- The fabrication processes involved are far less complex
- Fast, highly automated, suitable for large scale industrial production
- PE uses a small amount of conductive material and hence the cost is low

The major applications of PE are as follows:

- PE is widely used in Consumer Electronics
- It has significant applications in Pharmaceuticals and Packaging
- Touch screen displays (Wu & Jin,2011) (Ramakrishnan *et al.* 2011) benefit from PE technology
- PE is crucial for Radio Frequency Identification (RFID) tags (Rebros *et al.* 2008) (Aliga *et al.* 2011)
- Textiles incorporating electronic functionality use of PE
- Wearable skin sensors are designed using PE

- PE is used to create thin film transistors (Jiang *et al*. 2010) (Lin *et al*. 2012)
- It is used in several kinds of sensors and
- Photodetectors (Avuthu *et al*. 2016) are another significant application of PE

1.2 CLASSIFICATION OF PE

Considering the increasing quantity of disposable electronic gadgets, there is a growing need to reduce the amount of electronic waste produced. PE offers a significant potential to provide recyclable and biodegradable solutions (Tan *et al*. 2016) (Zeng *et al*. 2017) (Maddipatla *et al*. 2020). A new generation of flexible electronic applications is made possible by the great efficiency and compatibility of these technologies with polymeric materials (both substrates and inks). PE technologies can be categorized in two categories (Suganuma, 2014) (Machiels *et al*. 2019), as shown in Figure 1.2.

- Mask-based printing and
- Mask-less printing

Mask printing uses a mask, which is a stencil with a predetermined pattern, to transfer material onto a surface (Ostfeld et al. 2015) (Gengenbach et al.2020). It provides high accuracy and repeatability, making it suitable for applications that require complex formats in the way that masks are used. The printing plate is in direct contact with the surface. Processes such as flexographic printing SP gravure printing is just a few examples of printing using masks.

Maskless printing techniques do not rely on masks or stencils for pattern placement (Gengenbach et al. 2019) (Beedasy & Smith, 2020), but computer-aided drawing or design can be transformed into digital printing formats can be made using digital platforms. It serves as the necessary basis for these processes. Inkjet, aerosol, and direct printing are some of the printing methods.

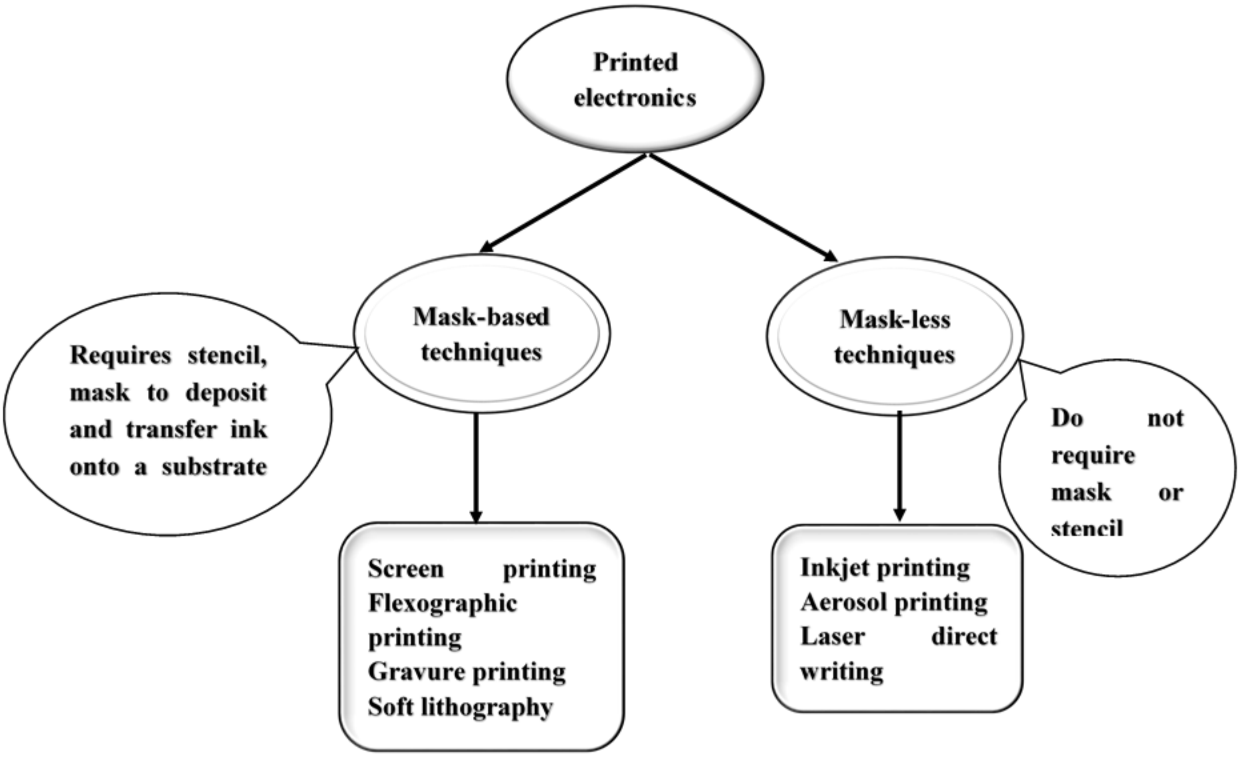

Figure 1.2 Classification of PE technologies

1.3 SCREEN PRINTING

Roll-to-roll (RTR) and Flat systems are two methods by which Screen Printing (SP), a flexible printing method, can be used. As shown in Figure 1.3. An SP and the substrate are in direct touch in the flat system. The mesh is filled with ink using a blade that moves and distributes the ink (Metters *et al.*2013) (Webb *et al.*2013). The ink flows from the mesh into the desired image and onto the substrate, defining the final image. Various substrates such as paper, glass, metal, ceramic, wood, textiles, and polymers can be used in SP, making it advantageous for printing on flexible or rigid substrates.

To cover every mesh aperture on the screen plate, inks are placed over it as shown in Figure 1.3. Subsequently, the mesh is pressed against the screen's back using a squeegee to move it to lower values. The capillary action controls how much ink is injected into the mesh holes. The strain on the back of the screen lessens as the squeegee advances, resulting in ink deposition on the substrate and forming the desired design. This printed design is further utilized in subsequent stages. Throughout the printing process, the inks undergo four essential processes such as filling, contact, adhesion, and release (Park *et al*. 2020).

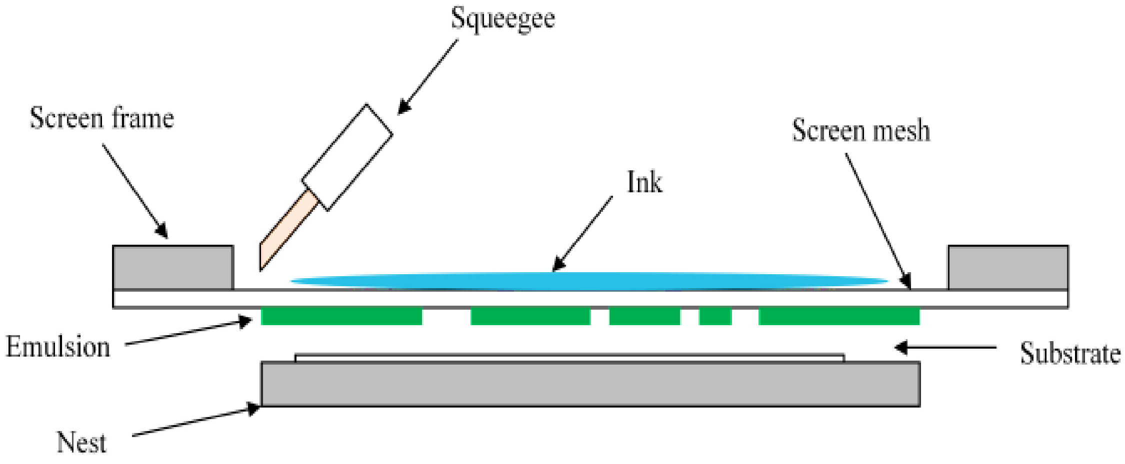

Figure 1.3 Screen printing

1.3.1 Why Screen Printing?

Screen printing stand out as a highly adaptable technique compared to other printing methods like flexography, gravure, and inkjet printing, as shown in figure 1.4. It offers versatility in printing on various surfaces such as paper, wood, plastic, cardboard, ceramics, leather, and metals (Suresh *et al*. 2021). Notably, it can print on both flat surfaces and diverse contours like round, convex, and irregular shapes, showcasing its unmatched ability to conform to surface characteristics. Unlike other direct printing methods, screen printing has maintained a steady presence in traditional markets despite the emergence of non-impact printing technologies that have affected flexography, inkjet, and gravure printing markets. One of its unique feature is the control over ink film thickness by adjusting the mesh fiber diameter, enabling the application of thick ink films. This technique covers a broad spectrum of inks, ranging from those used in typical graphic arts to specialized conductive inks for electronics (Zhang *et al*.2018). In contrast, gravure and flexographic processes necessitate more complex ink formulations.

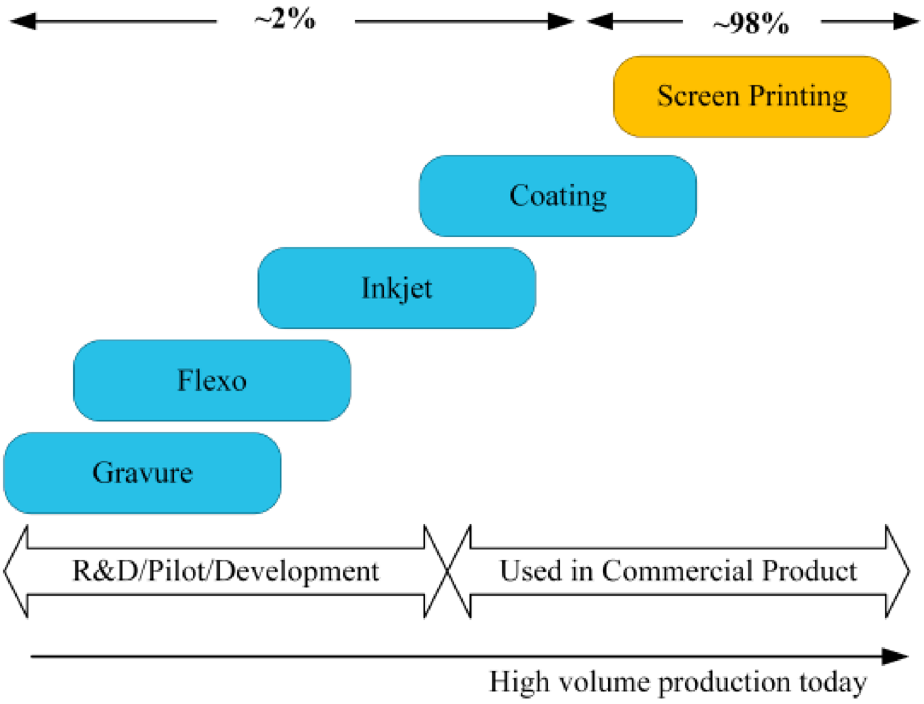

Figure 1.4 Contribution of SP as per the report from IDTechEx on printed and flexible electronics forecasts, player, and opportunities 2017-2027.

1.4 CONDUCTIVE INKS

Conductive inks find primary applications in the field of PE, where they are employed to create printed circuits. Formulating conductivity inks involves complex compositions comprising various components. The conducting substance, which might be made of metal, carbon, or conductive polymers, is the primary component (Wood *et al*. 2005) (Kattumenu,2008). Resins are used to distribute the conductive particles throughout the ink and provide it with mechanical and sticky qualities. To dissolve the resins and control the rheological properties of the ink, solvents are added, while additives are incorporated to fine-tune process ability or functional attributes (Joshi,2011) (Bhore,2015) (Rossal & Wallner,2019).

1.4.1 Silver Ink

Silver based inks are known for their exceptional flexibility and high conductivity, with silver being the most conductive metal at 6.28 X 10^7 S/m. In addition to its conductivity, silver exhibits superior performance compared to other metals in oxidative conditions, as the oxide layer formed during curing remains conductive. Silver based inks are highly durable under various conditions and demonstrate excellent mechanical adhesion to different substrates, making them ideal for use in electronic products.

Compared to bulk metals, silver is nano-sized particles requires lower sintering temperatures for consolidation. Typically, the sintering procedure requires temperatures between 100 to 300° C to eliminate organic compounds from nanoparticle inks, producing a low-resistance conductive film and a silver layer that is closely packed. The sintering time generally varies from 20 minutes to 2 hours. During sintering, the temperature at which the printed patterns become empty of biological shells for the particles is raised, rapidly reducing resistance via direct physical contact and achieving conductance.

Sintering at temperature between 200 to 250°C, yields conductive closer to bulk silver. However, this limits substrate options, as silver is compatible with plastic substrates only at sintering temperature below 160°C. Despite this limitation, films with good conductivities can be achieved at such temperature.

1.4.2 Copper Ink

Silver-based inks are more expensive than copper-based inks, which have a similar conductivity level. They may be used to print electrical circuits in a variety of electronic devices since they also exhibit high adherence to different substrate materials. However, copper is prone to oxidation and copper oxide is an insulator. This means that as copper oxidizes, its conductivity decreases. Therefore, it is crucial to include protective chemicals in the ink formulation to slow down the oxidation process. Additionally, applying a topcoat to printed copper patterns is necessary to prevent the formation of copper oxide over time.

Printed copper circuits acquire a metallic appearance and improve in conductivity as they dry. Sintering is crucial for enhancing the conductivity of copper-based inks as it accelerates the process of drying and preventing the creation of the copper oxide layer that acts as insulation. Sintering at temperature around 350°C is necessary to achieve conductivity levels close to the bulk material. However, at a temperature of 250°C, beneficial sintered copper structures are possible. Using copper-based inks on plastic substrates at a temperature lower than 160°C is comparable to using silver-based inks. However, finding a balance between substrate compatibility and conductivity is essential.

1.4.3 Carbon Ink

While carbon-based inks possess conductivity, they exhibit relatively high resistance levels. This limits their suitability for many applications in PE, especially for patterning electrical circuits. Moreover, these inks often have issues with insufficient cohesiveness within the ink layer and poor adherence to surfaces, leafing to reduced flexibility and resistance to abrasion. Their limited capacity to process substantial volumes of data renders them inappropriate for use in real-world applications.

Despite these challenges, the expanding area of PE offers a great deal of potential uses for carbon-based inks. When paired with other conductive inks, such as those based on silver, they facilitate the construction of resistors, can be used to fabricate resistor circuits suitable for printing on various low-temperature substrates. Their affordability makes them a viable option for producing cost-effective biosensors, particularly in the competitive market for disposable sensors. To improve the conductivity of carbon-based inks, layering techniques can be employed. These inks may reach their maximal conductivity after drying, which usually takes 10 to 15 minutes at room temperature.

1.5 COMPUTATIONAL INTELLIGENCE TECHNIQUES

Computational intelligence techniques encompass a diverse set of methodologies that emulate human like intelligence to solve complex problems. As they can be used to solve problems in a variety of fields, such as engineering, finance, and medicine, these approaches have become very popular. Computational intelligence involves the design and application of computational models inspired by biological and cognitive processes. Unlike conventional methods, which depends on instructions and rules, computational intelligence techniques use data-driven learning and optimization to achieve better results. Computational intelligence techniques typically blend various paradigms like Artificial Neural Network (ANN), fuzzy systems, evolutionary computation, and more. These systems often aim to imitate aspects of biological intelligence. Furthermore, computational intelligence is closely linked to adaption, encompassing practical concepts, algorithms, and implementations for adaption and self-organization that facilitate intelligent actions in complex and dynamic environments.

1.5.1 Artificial neural network

Computer architectures are indicated to imitate the activity of genuine neurons as ANNs. Their composition consists of a multitude of interconnected processing units, often referred to as neurons, that function simultaneously and are grouped in predictable ways. An ANN's collective behavior, like that of a human brain, exhibits the capacity to learn from, remember, and extrapolate from training data. The key strength of ANN is their ability to extract hidden information from data, where many traditional methods struggle. Many different types of neuronal cells in the human brain process information. Every cell functions as a basic processor. The brain's capacity is only made feasible by the vast interaction and parallel processing across all cells (Dastres & Soori, 2021). Figure 1.5 shows many components of a biological neural network.

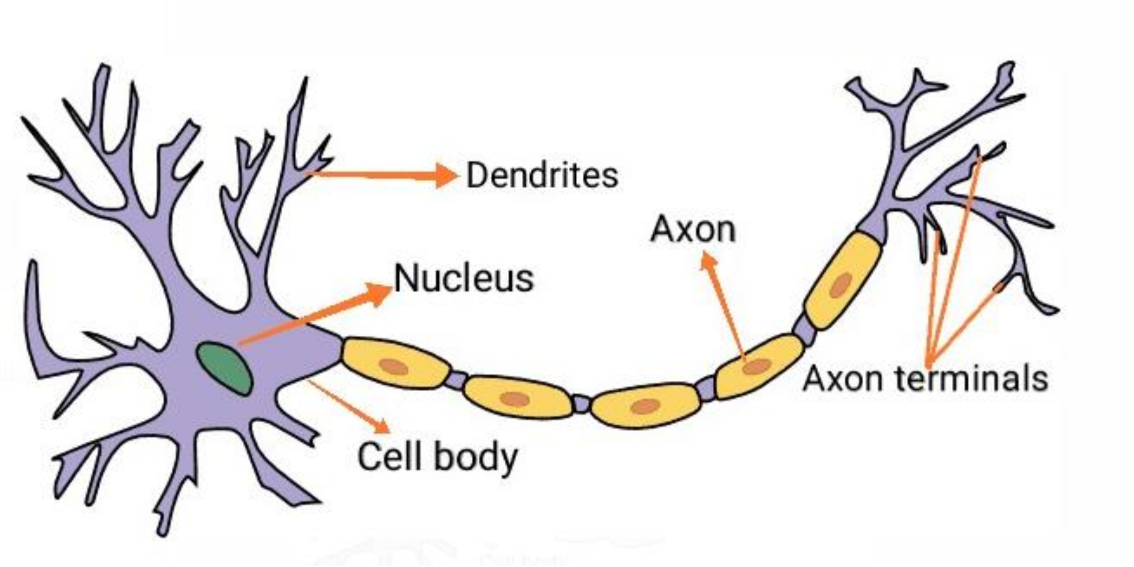

Figure 1.5 Biological neuron

The structure of the ANN is inspired by biological neurons. Fibers that branch out of the cell body, or soma, are known as dendrites. An axon distributes impulses to other neurons from a biological neuron's cell body, or soma, which processes the impulses. Dendrites receive the impulses. The nucleus and other components that facilitate chemical processing and neurotransmitter synthesis are located in the cell body of a neuron. An axon is a single fiber that travels from the soma to the locations where other neurons, muscles, or glands synoptically receive information.

The term "ANN" describes an artificial intelligence subfield that draws inspiration from biology, specifically the brain. The structure of the human brain is built on biological neural networks, which serve as the basis, are often the source of an ANN's computational architecture. Neurons in artificial neural networks (ANNs) are linked to one another at different levels of the network, the same as neurons in a real brain. A neuron's dendrites are an ANN's representation of its inputs. Axon stands for output, Synapse for weights, and Cell for nodes.

Artificial neurons are mathematical abstractions designed to imitate the behavior of real biological neurons within an ANN. McCulloch-Pitts neurons which is the appropriate form of natural nerve cells. It is one of the basic models of artificial neurons, the McCulloch-Pitts model. It consists of several important components such as the input layer, output layer, weights, boundaries, and activation functions are the basic components of artificial neurons in ANN. The connection strength between neurons is determined by the weights. This affects the amount that each input contributes to the activation of the neuron. Bias provides another layer of control over neuronal activation. This makes it possible to adjust the response to inputs. The activation function acts as a nonlinear transformation. It determines the output using a weighted sum of the inputs and neuronal regions. The ANN model is derived from the principles of biological brain systems. This shows the connection between artificial neurons. and their role in transmitting information and resources within the network.

Advantages of ANNs

- **Parallel processing capabilities:** The numerical capabilities of ANNs allow them to perform multiple tasks simultaneously.
- **Ability to work with incomplete knowledge:** Even with enough data, the ANN can produce data results after training.
- **Flexibility:** ANN's ability to handle complex and irreversible relationships between input vectors and output labels is excellent.
- **Scalability:** Large datasets can be processed quickly by ANNs and deep structures can be trained with millions of parameters. ANNs are also highly scalable.
- **Adaptability:** ANNs can develop hierarchical representations from raw data and work very well in situations that require complex modeling and extensive data exploration.
- **Accuracy:** Although sacrificing the interpretability of the model, ANNs can be used in situations where accuracy is important.

1.5.2 Support vector machine

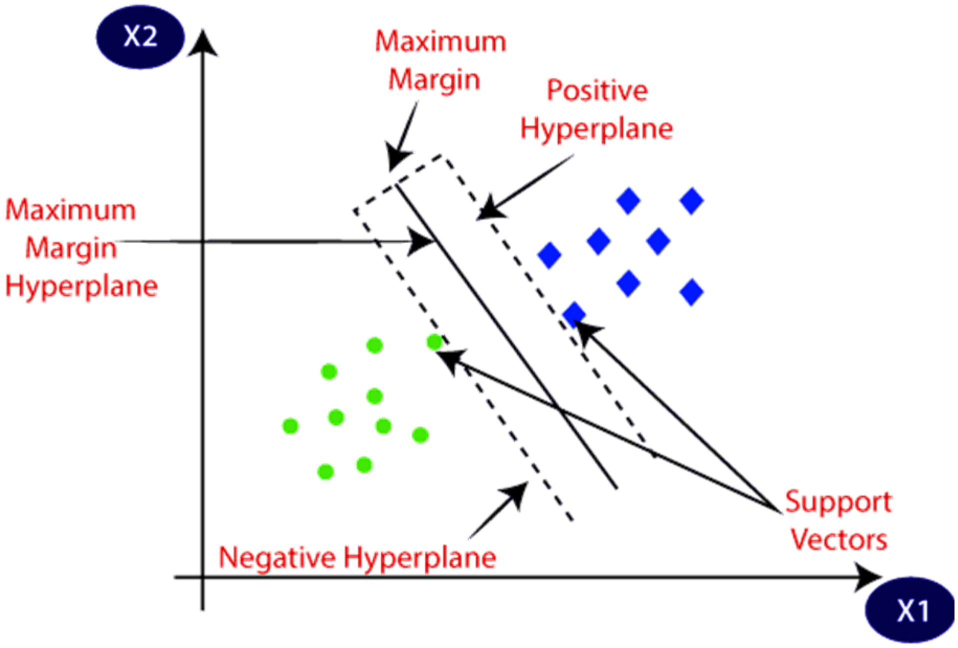

Figure 1.6 SVM model

A potent machine learning classifier is the SVM. It may be used for the resolution of issues involving classification and regression. Finding the optimal line, or hyperplane, to partition n-dimensional space into distinct classes is the SVM's main objective. SVM uses the extreme examples, or support vectors, that help create the hyperplane to identify. Figure 1.7 shows two different cases being classified by a hyperplane. Non-linear SVM and linear SVM are the two types of SVM. Non-linear SVM is used to classify datasets that may be accurately categorized using a single straight line, whereas linearly separable data are classified using linear SVM.

SVM approach for data categorization

The SVM method classification procedure step-by-step:

1.Data representation: A collection of features that identify each data point as belonging to one of two classes is what SVMs need for labeled training data.

2.Feature mapping: If the data cannot be linearly separated in its original feature space, a kernel function may be used in SVM to translate the data onto a higher dimensional space. A linear hyperplane in the new space that correlates to a nonlinear decision boundary in the old space may be found by the SVM due to this transformation.

3.Optimizaion objective: The margin between two classes' support vectors is what SVM seeks to optimize. According to data that has been seen, the margin is the distance, in each class, between the nearest data point and the hyperplane.

4.Kernel trick: The application of kernel functions transforms a higher dimensional space from the initial feature space. SVM can handle nonlinear decision boundaries successfully. The dataset and needed decision boundary complexity influence the kernel function selection.

5.Margin maximization: SVM locates the hyperplane that maximizes the margin while simultaneously separating the data during training. Better generalization to previously unknown data and the classifier's resilience are ensured by this margin maximization.

6.Support vectors: The sets of data features support vectors are those that are closest to the interfaces. They are used to forecast fresh data points and are essential in creating the hyperplane.

7.Regularization parameter C: In SVM, the regularisation parameter C balances the maximization of the categorisation error's margin and reduction. Although a larger C imposes a more rigid boundary, a lower C permits a broader buffer. The regularization parameter is used to prevent the model from overfitting and enhance its capacity for generalization.

8.Prediction: Determining which side of the hyperplane new data points fall on, SVM may predict the class label of those data points after it has been trained.

Advantages of SVM

- Even in situations when there are more characteristics than samples, SVM operates effectively. It handles high-dimensional data without suffering from the curse of dimensionality as much as other algorithms.

- Training process is simple. It is an effectively defined and manageable procedure to find the optimum margin between classes hyperplane.
- SVM can handle large feature spaces effectively, making it suitable for applications like text classification
- SVM is highly versatile and performs well even with unstructured and semi structured data.
- SVM has a regularization parameter that helps control the decision boundary’s complexity and reduce the risk of overfitting.
- SVM can classify data in both linear and non-linear methods since it can translate input data into higher-dimensional spaces using kernel methods.

1.5.3 Particle swarm optimization

Emerging collective intelligence between simple agent groupings is called swarm intelligence. Self-organized and decentralized systems exhibit collective intelligence in their behavior. Social insects that construct their nests, travel in groups, sort and cluster collectively, and engage in group foraging are examples of swarm intelligence algorithms. Numerous domains, including data clustering, have seen the effective use of swarm intelligence algorithms, classification, signal processing, decision support, optimization, and so on. The main features of the swarm intelligence algorithm are: (i) strong robustness (ii)simple and easy to implement (iii) good scalability and (iv) strong self-organization. Several swarm optimization algorithms are available such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), and so on. Amidst, PSO is used in this research work due to its simplicity, few parameters, and competitive performance.

Swarm intelligence and mobility serve as the foundation for PSO, a resilient stochastic optimization method. Problem resolution is approached via the perspective of social interaction. PSO uses a swarm of agents to move about the search space to find the best solution. Every particle in N-dimensional space is seen as a point that modifies its flying behavior based on both its own and other particles' flying experiences. PSO can effectively search the search space and converge to the nearly ideal solutions because of this combination of individual and group learning. Particles, fitness function, location update, velocity update, global best and local best are the essential parts of PSO. The PSO method excels in solving high-dimensional and nonlinear optimization problems because of its simplicity, ease of use, and efficacy. It is a popular option for optimizing complicated systems and functions because of its capacity to achieve a balance between exploration and exploitation.

1.5.4 Deep learning

Deep learning has transformed different sectors by letting computers learn from and make conclusions from huge amounts of data. Using model architectures, this system is built around techniques that aim to capture high-level abstractions in data, sophisticated structures or other methods that are constructed from a number of neural networks. Deep learning algorithms automatically discover complex patterns and representations straight from raw data, such as text, music, and images, in contrast to traditional machine learning algorithms that depend on manual feature extraction. The phrase "deep learning" refers to ANNs with many layers. The way the human brain is organized and functions especially in terms of its networked neurons and hierarchical processing is an inspiration for these networks. Deep neural networks develop complicated connections and representations by extracting more abstract elements from the input data at each layer. Deep learning has gained prominence due to several key factors such as feature learning, scalability, performance, versatility, and continuous learning. Deep neural networks with the highest level of popularity and use are as follows:

- Convolutional Neural Networks (CNNs)
- Deep Belief Networks (DBNs)
- Recurrent Neural Network (RNN)

- Auto Encoders (AEs) and
- Long Short-Term Memory (LSTM)

The CNN, a distinctive kind of deep learning model, consists of one or more levels with subsampling layers that are succeeded by one or more layers that are completely related. CNNs are often used in computer vision applications. The grid-like matrix dataset's characteristics are mostly extracted using the ANN. Figure 1.8 depicts the main layout of CNN.

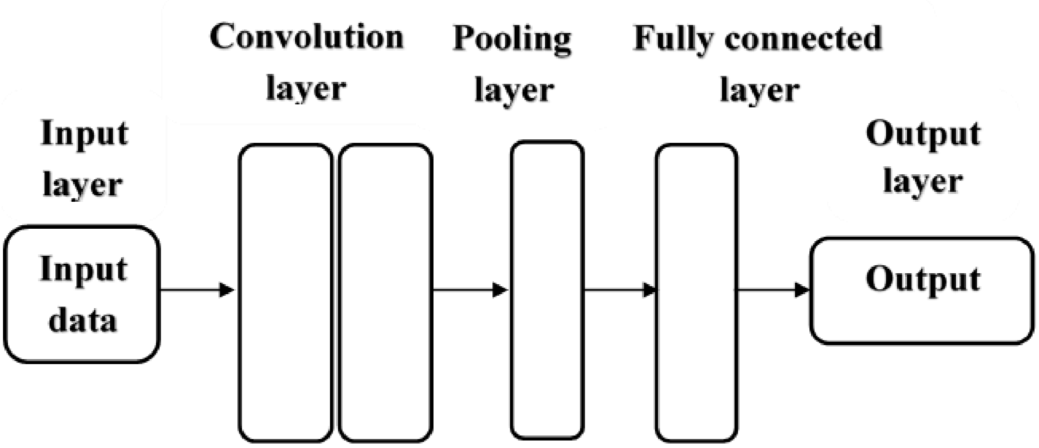

Figure 1.7 Architecture of CNN

1.Convolutional layer

Initially, additional features are extracted from the input data using the convolutional layer. In between a certain size filter and the input data, N X N, it executes a convolution operation. The filter is slid over the input data to produce the dot product, therefore taking into account the sections of the input image that are affected by the filter. Given information about the input data, the output is referred to as features. Identifying additional characteristics from the input data, this feature is later fed to other layers. After the input has undergone the convolution process, the subsequent layer receives the convolution layer's output.

2. Pooling layer

Typically, the pooling layer follows the convolution layer. The major function of this layer is to reduce feature sizes to achieve cost savings in computation. This is achieved by breaking down the connections between the layers and performing individual operations on each feature map.

3.Fully connected layer

The completely linked layer encompasses of connected neurons between two separate layers by means of the weights, biases, and neurons involved. Typically, these layers are placed before the output layer in a CNN, serving as the last levels. The completely connected layer receives input characteristics that have been flattened from the preceding levels. After going through a couple more completely linked layers, the flattened vector is classified.

4.Activation function

The activation function is one of the CNN's most crucial parameters. They are used to discover and estimate all continuous and comprehensive relationships between network variable types. The system determines which model information should be sent across the network and which should not. Functional activation increases network non-linearity. Sigmoidal, softmax, and ReLU activation functions are common. Each of these functions have a specific usage. Selection activation function depends on the application.

To select conductive inks for printing applications based on material properties, machine learning and optimization techniques can be highly effective in making informed decisions. Classification issues are the primary focus of the SVM model, which is a form of supervised learning model. Optimizing the margin between the classes determines which hyperplane in the input data optimally divides the various classes. In the context of conductive ink selection, SVM can classify the types of inks based on material properties. Numerous layers of nodes have activation functions that make up an ANN, enabling it to model complex relationship in data. Classification and regression problems are two typical uses for it. ANN can learn the underlying patterns in the material properties and predict which type of ink is most suitable for a specific application.

PSO is an optimization technique that draws inspiration from fish schools and flocks of birds. An optimum solution to a problem is achieved via the process of constantly improving a prospective solution about defined quality criteria. In this context, the ANN's weights and biases are optimized using PSO. By finding the optimal parameters, PSO-ANN can improve the accuracy of predicting the best flowing ink based on material properties. The ability of an ANN to accurately summarize and predict is enhanced when PSO helps the ANN determine ideal parameters. This is particularly useful in situations where material properties may have complex and nonlinear interactions. This requires a finely tuned model to capture.

Deep learning models automatically extract the most important features from the input data using convolution layers. Regression or classification is applied to while pooling layers are used to reduce dimension, entirely connected layers are used. Deep learning may be used to extract spatial feature hierarchies from input data related to material qualities. Deep learning model detects patterns in the sequence of material properties that are indicative of the most suitable ink. Using deep learning has the advantage of automatically identifying important features. And there is no need to manually extract features.

ANN can model how input parameters and output variables relate to each other. Particularly useful for complex non-linear relationships. Based on the input features, SVM can be used to classify different types of conductive inks. Using a dataset of known inks, an SVM model is trained and can predict the best ink type for a given application. The PSO algorithm can optimize the parameters of the ANN to achieve the results. as desired deep learning can model the non-linear relationship between input variables and performance. Leads to high accuracy selection. Using these models, the conductor ink selection process will be more efficient and accurate for specific application requirements in PE.

1.6 MOTIVATION OF THE RESEARCH

PE has gained a lot of attention from the industry due to its outstanding ability to produce electro photonic devices using innovative printing techniques such as inkjet and screen printing along with conductive inks. This helps determine the quality of the final product. Printing flexible electronic circuits increasing the communication capabilities of products and guarantee of overall product quality it all depends on the proper use of conductive ink. Selecting the right conductive ink is critical to meeting customer needs and maintaining product competitiveness in the market. The traditional method of selecting permeable ink is labour intensive, time consuming and requires manual labour. This makes this method dependent on the manufacturer's design knowledge. ineffective and often leads to the selection of inappropriate materials. Therefore, it is necessary to develop an automated system for selecting conductive inks to overcome the limitations of manual methods.

The main motivation behind this research is to create an automatic neural network-based method for driver ink selection. Metaheuristic algorithm and deep learning methods. These state-of-the-art techniques make it possible to improve decision-making processes and optimize outcomes. By creating an automatic ink selection method. This research aims to increase the efficiency of the ink selection process, reduce time, clear the way for development in the field of PE, and support technological innovation.

1.7 STATEMENT OF THE PROBLEM

Although PE is becoming increasingly important across industries, but current approaches to conductive irrigation are still manual and inefficient. These traditional methods rely heavily on human expertise, cannot be resized and are prone to errors. This reliance on manual processes not only slows down technological progress but it also hinders the potential of PE-derived products. The lack of automated tools for conductive irrigation leaves a significant gap in the field. This limits the potential of printed electronic devices. This gap highlights the critical need to develop a specially designed automation system to improve and improve conductive irrigation processes for PE applications.

The proposed concept of an automatic conductive ink selection system aims to close this gap. The high quality and reliability of PE products depends greatly on this success, which is important to meet the ever-changing needs of customers.

1.8 RESEARCH OBJECTIVES

The main goal of this research is to develop an automated system for conductive irrigation in PE using various advanced algorithms including artificial neural networks, natured inspired, and deep learning models. The main goals of the research are briefly described below.

- To create a conductive ink selection in printed electronics using MLPNN and SVM independently.
- To combine MLPNN with PSO algorithm to design a model for selecting conductive ink in printed electronic devices.
- To model conductive ink selection system in printed electronic devices using a deep learning approach.

According to these objectives, the research aims to advance the PE field by creating an intelligent system that can efficiently and accurately select conductive inks. To improve automation and increase efficiency in the use of PE.

1.9 ORGANIZATION OF THE THESIS

This thesis explains the design and implementation of an automated systems for choosing conductive ink for PE applications by employing neural network, metaheuristic algorithm, and deep learning model. The frameworks proposed in this research have been implemented and validated, and demonstrated to be effective based on evaluation criteria. The following systematizes the thesis:

Chapter 1 deals with the introduction to printed electronics and screen printing. Automated system for conductive inks selection and its various phases are discussed. The motivation and objectives of the research are given. Finally, the outline of the thesis is presented.

Chapter 2 covers a complete review of various works in the domain of PE. The state-of-the-art methods for choosing conductive ink for PE applications is discussed in this chapter.

Chapter 3 explains the details of the input and output variables used in this research. It also highlights the novel contributions proposed in this research concerning conductive ink selection for PE applications.

Chapter 4 delineates a conductive ink selection system based on neural network. A detailed description of the developed system is presented. Effectiveness of the MLPNN and SVM are assessed by computing accuracy, precision, recall, F1-score, balanced classification rate, and miss classification rate. Additionally, the obtained results are compared to find out the suitable system for conductive ink selection.

Chapter 5 details the proposed methodology employing MLPNN and PSO to choose conductive ink for PE applications. This model's superiority is shown by evaluating and comparing its performance to that of the other models.

Chapter 6 describes how a deep network is employed in an automated manner to choose conductive ink. Efficacy of this model is measured and compared with other models to assess its performance.

Chapter 7 compares the results obtained from developed models with respect to accuracy, recall, precision, F1-score, balanced classification rate, and miss classification rate. Assessing the benefits and drawbacks of each approach is possible through this comparison study.

Chapter 8 gives a succinct overview of the study project and makes conclusions based on the findings in the thesis. Additionally, a few areas for future investigations and research directions are suggested in this chapter.

1.10 CHAPTER SUMMARY

This chapter explains the fundamental concepts of PE and explores various techniques employed in device fabrications within this domain. It also delves into SP and highlights the importance of conductive inks in PE applications, presents a problem statement and motivation. Additionally, this chapter discusses specific research goals and presents a structured overview of the thesis.