Other emerging technologies

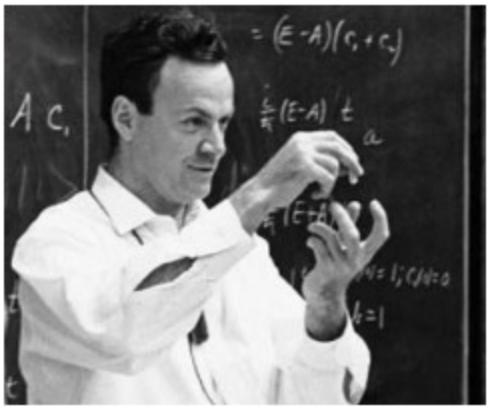
1. Nanotechnology

Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers[39].

Nanoscience and nanotechnology are the study and application of extremely small things and can be used across all the other science fields, such as chemistry, biology, physics, materials science, and engineering[39].

7.1.1 How it started

The ideas and concepts behind nanoscience and nanotechnology started with a talk entitled "There's Plenty of Room at the Bottom" by physicist Richard Feynman at an American Physical Society meeting at the California Institute of Technology (CalTech) on December 29, 1959, long before the term nanotechnology was used. In his talk, Feynman described a process in which scientists would be able to manipulate and control individual atoms and molecules. Over a decade later, in his explorations of ultraprecision machining, Professor Norio Taniguchi coined the term nanotechnology. It wasn't until 1981, with the development of the scanning tunneling microscope that could "see" individual atoms, that modern nanotechnology begun[39].



F.Physicist Richard Feynman, the father of nanotechnology[39]

7.1.2 Fundamental concepts in nanoscience and nanotechnology

IT'S HARD TO IMAGINE JUST HOW SMALL NANOTECHNOLOGY IS. ONE NANOMETER IS A BILLIONTH OF A METER OR 10^{-9} OF A METER. HERE ARE A FEW ILLUSTRATIVE EXAMPLES[39]:

1. There are 25,400,000 nanometers in an inch

2. A sheet of newspaper is about 100,000 nanometers thick

3. On a comparative scale, if a marble were a nanometer, then one meter would be the size of the Earth

Nanoscience and nanotechnology involve the ability to see and to control individual atoms and molecules. Everything on Earth is made up of atoms—the food we eat, the clothes we wear, the buildings and houses we live in, and our own bodies[39].

But something as small as an atom is impossible to see with the naked eye. In fact, it’s impossible to see with the microscopes typically used in high school science classes. The microscopes needed to see things at the nanoscale were invented relatively recently—about 30 years ago[39].

As small as a nanometer is, it's still large compared to the atomic scale. An atom has a diameter of about 0.1 nm. An atom's nucleus is much smaller -- about 0.00001 nm. Atoms are the building blocks for all matter in our universe. You and everything around you are made of atoms. Nature has perfected the science of manufacturing matter molecularly. For instance, our bodies are assembled in a specific manner from millions of living cells. Cells are nature's nanomachines. At the atomic scale, elements are at their most basic level. On the nanoscale, we can potentially put these atoms together to make almost anything[40].

In a lecture called "Small Wonders:The World of Nanoscience," Nobel Prize winner Dr. Horst Störmer said that the nanoscale is more interesting than the atomic scale because the nanoscale is the first point where we can assemble something -- it's not until we start putting atoms together that we can make anything useful[40].

People are interested in the nanoscale – which we define to be from 100nm down to the size of atoms (approximately 0.2nm) – because it is at this scale that the properties of materials can be very different from those at a larger scale. We define nanoscience as the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale; and nanotechnologies as the design, characterisation, production and application of structures, devices and systems by controlling shape and size at the nanometer scale[41].

The properties of materials can be different at the nanoscale for two main reasons[41]:

1. First, nanomaterials have a relatively larger surface area when compared to the same mass of material produced in a larger form. This can make materials more chemically reactive (in some cases materials that are inert in their larger form are reactive when produced in their nanoscale form), and affect their strength or electrical properties.

2. Second, quantum effects can begin to dominate the behavior of matter at the nanoscale – particularly at the lower end – affecting the optical, electrical and magnetic behavior of materials. Materials can be produced that are nanoscale in one dimension (for example, nanowires, nanorods, and nanotubes), in two dimensions (plate-like shapes like nanocoatings, nanolayers, and graphene) or in all three dimensions (for example, nanoparticles).

Today's scientists and engineers are finding a wide variety of ways to deliberately make materials at the nanoscale to take advantage of their enhanced properties such as higher strength, lighter weight, increased control of light spectrum, and greater chemical reactivity than their larger-scale counterparts[39].

7.1.3Applications of nanotechnology:

1. Medicine

Researchers are developing customized nanoparticles the size of molecules that can deliver drugs directly to diseased cells in your body. When it's perfected, this method should greatly reduce the damage treatment such as chemotherapy does to a patient's healthy cells[42].

2. Electronics

Nanotechnology holds some answers for how we might increase the capabilities of electronics devices while we reduce their weight and power consumption[42].

3. Food

Nanotechnology is having an impact on several aspects of food science, from how food is grown to how it is packaged. Companies are developing

nanomaterials that will make a difference not only in the taste of food but also in food safety and the health benefits that food delivery[42].

4. Space

Nanotechnology may hold the key to making space-flight more practical. Advancements in nanomaterials make lightweight spacecraft and a cable for the space elevator possible. By significantly reducing the amount of rocket fuel required, these advances could lower the cost of reaching orbit and traveling in space[42].

5. Agriculture

Uses of nanotechnology can possibly change the whole agriculture part and nourishment industry anchor from generation to preservation, handling, bundling, transportation, and even waste treatment. NanoScience ideas and Nanotechnology applications can possibly update the generation cycle, rebuild the preparing and protection forms and rethink the nourishment propensities for the individuals[43].

6. Vehicle manufacturers

Much like aviation, lighter and stronger materials will be valuable for making vehicles that are both quicker and more secure. Burning motors will likewise profit from parts that are all the more hardwearing and higher temperature safe[43].

7. Construction

Nanotechnology can possibly make development quicker, less expensive, more secure, and more changed. Computerization of nanotechnology development can take into account the formation of structures from cutting edge homes to enormous high rises substantially more rapidly and at much lower expense[43].

8. Information and communication

Current high-innovation generation techniques are in view of customary top-down procedures, where nanotechnology has as of now been presented noiselessly. The basic length size of incorporated circuits is as of now at the nanoscale (50 nm and underneath) with respect to the entryway length of transistors in CPUs or DRAM gadgets[43].

9. Medicine

The scientific and scientific analysis areas have utilized the exclusive qualities of nanomaterials for various programs (e.g., comparison providers for mobile pictures and therapeutics for the treatment of cancer). Conditions such as biomedical nanotechnology, bionanotechnology, and nanomedicine are used to explain these multiple areas. Features can be included in nanomaterials by interfacing them with scientific elements or components. The size of nanomaterials is just like that of most scientific elements and structures; therefore, nanomaterials can be useful for both in vivo and in vitro biomedical analysis and programs. Thus far, the incorporation of nanomaterials with chemistry has led to the growth of analytic gadgets, comparison providers, systematic resources, actual physical rehabilitation programs, and medication distribution automobiles[43].

10. Biotechnology

It is the broad area of biology involving living systems and organisms to develop or make products, or "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use"[44].

At its simplest, biotechnology is technology based on biology - biotechnology harnesses cellular and biomolecular processes to develop technologies and products that help improve our lives and the health of our planet. We have used the biological processes of microorganisms for more than 6,000 years to make useful food products, such as bread and cheese, and to preserve dairy products[45].

Brewing and baking bread are examples of processes that fall within the concept of biotechnology (use of yeast (= living organism) to produce the desired product). Such traditional processes usually utilize the living organisms in their natural form (or further developed by breeding), while the more modern form of biotechnology will generally involve a more advanced modification of the biological system or organism[46].

One example of modern biotechnology is genetic engineering. Genetic engineering is the process of transferring individual genes between organisms or modifying the genes in an organism to remove or add a desired trait or characteristic[47].

Today, biotechnology covers many different disciplines (eg. genetics, biochemistry, molecular biology, etc.). New technologies and products are

developed every year within the areas of eg. medicine (development of new medicines and therapies), agriculture (development of genetically modified plants, biofuels, biological treatment) or industrial biotechnology (production of chemicals, paper, textiles, and food)[46].

7.2.1 History

When Edward Jenner invented vaccines and when Alexander Fleming discovered antibiotics, they were harnessing the power of biotechnology. And, of course, modern civilization would hardly be imaginable without the fermentation processes that gave us beer, wine, and cheese![48]

When he coined the term in 1919, the agriculturalist Karl Ereky described 'biotechnology' as "all lines of work by which products are produced from raw materials with the aid of living things." In modern biotechnology, researchers modify DNA and proteins to shape the capabilities of living cells, plants, and animals into something useful for humans. Biotechnologists do this by sequencing or reading, the DNA found in nature, and then manipulating it in a test tube – or, more recently, inside of living cells[48].

7.2.2 Application of biotechnology

1. Agriculture

The use of Biotechnology in Agriculture is known as Green Biotechnology. Biotechnology had contributed a lot towards the upliftment of agriculture. The organisms formed after manipulation of genes is known as Genetically Modified Organisms such as Crops, Animals, Plants, Fungi, Bacteria, etc. Genetically modified crops are formed by the manipulation of DNA to introduce a new trait into the crops. These manipulations are done to introduce traits such as pest resistance, insect resistance, weed resistance, etc[49].

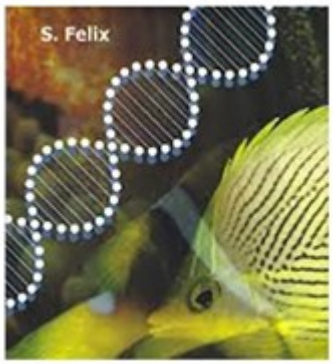
2. Medicine

The use of biotechnology in medicine is known as Medicinal Biotechnology. This helps in the formation of genetically modified insulin known as humulin. This helps in the treatment of a large number of diabetes patients[49].

Biotechnology has given rise to a technique known as gene therapy. Gene therapy is a technique to remove the genetic defect in an embryo or child. This technique involves the transfer of a normal gene that works over the non-functional gene[49].

3. Aquaculture Fisheries

It helps in improving the quality and quantity of fishes. Through biotechnology, fishes are induced to breed via gonadotropin-releasing hormone[49].



1. Growth Enhancement
2. Genetic Characterization
3. Control of Diseases
4. Metabolic Engineering
5. Transgenesis

1. Production of Antibiotics

Plants are used to develop antibiotics for Humans as well as for Animal use. It helps in the production of antibiotics, vaccines and artificial hormones for hormone therapies[49].

2. Environment

Environmental biotechnology is used in waste treatment and pollution prevention. Environmental biotechnology can more efficiently clean up many wastes than conventional methods and greatly reduce our dependence on methods for land-based disposal[47].

Every organism ingests nutrients to live and produces by-products as a result. Different organisms need different types of nutrients. Some bacteria thrive on the chemical components of waste products. Environmental engineers use bioremediation, the broadest application of environmental biotechnology, in two basic ways. They introduce nutrients to stimulate the activity of bacteria already present in the soil at a waste site or add new bacteria to the soil. The 5 bacteria digest the waste at the site and turn it into harmless byproducts. After the bacteria consume the waste materials, they die off or return to their normal population levels in the environment.

2. Blockchain technology

3. Cloud and quantum computing

7.5 Autonomic computing (AC)

Autonomic computing (AC) is an approach to address the complexity and evolution problems in software systems. A software system that operates on its own or with a minimum of human interference according to a set of rules is called autonomic.1 The term autonomic derives from the human body's autonomic nervous system, which controls key functions without conscious awareness or involvement[50].

It refers to the self-managing characteristics of distributed computing resources, adapting to unpredictable changes while hiding intrinsic complexity to operators and users. Initiated by IBM in 2001, this initiative ultimately aimed to develop computer systems capable of self-management, to overcome the rapidly growing complexity of

computing systems management, and to reduce the barrier that complexity poses to further growth[51].

Autonomic computing is a self-managing computing model named after, and patterned on, the human body's autonomic nervous system. An autonomic computing system would control the functioning of computer applications and systems without input from the user, in the same way, that the autonomic nervous system regulates body systems without conscious input from the individual. The goal of autonomic computing is to create systems that run themselves, capable of high-level functioning while keeping the system's complexity invisible to the user[52].

7.5.1 Characteristics of Autonomic Systems

An autonomic system can self-configure at runtime to meet changing operating environments, self-tune to optimize its performance, self-heal when it encounters unexpected obstacles during its operation, and—of particular current interest—protect itself from malicious attacks. An autonomic system can self-manage anything including a single property or multiple properties[50] (see picture below).



F. Autonomic Characteristics

Discuss briefly each of the characteristics of the autonomic system

Autonomic systems/applications exhibit eight defining characteristics[53]:

1. Self Awareness: An autonomic application/system “knows itself” and is aware of its state and its behaviors.
2. Self Configuring: An autonomic application/system should be able to configure and reconfigure itself under varying and unpredictable conditions.
3. Self Optimizing: An autonomic application/system should be able to detect suboptimal behaviors and optimize itself to improve its execution.
4. Self-Healing: An autonomic application/system should be able to detect and recover from potential problems and continue to function smoothly.
5. Self Protecting: An autonomic application/system should be capable of detecting and protecting its resources from both internal and external attacks and maintaining overall system security and integrity.
6. Context-Aware: An autonomic application/system should be aware of its execution environment and be able to react to changes in the environment.
7. Open: An autonomic application/system must function in a heterogeneous world and should be portable across multiple hardware and software architectures. Consequently, it must be built on standard and open protocols and interfaces.
8. Anticipatory: An autonomic application/system should be able to anticipate to the extent possible, its needs and behaviors and those of its context, and be able to manage itself proactively

7.6 Computer vision

A bit of history

The origins of computer vision go back to an MIT undergraduate summer project in 1966. It was believed at the time that computer vision could be solved in one summer, but we now have a 50-year old scientific field that is still far from being solved[54].

Early experiments in computer vision took place in the 1950s, using some of the first neural networks to detect the edges of an object and to sort simple objects into categories like circles and squares. In the 1970s, the first commercial use of computer vision interpreted typed or handwritten text

using optical character recognition. This advancement was used to interpret written text for the blind[55].

As the internet matured in the 1990s, making large sets of images available online for analysis, facial recognition programs flourished. These growing data sets helped make it possible for machines to identify specific people in photos and videos[55].

7.6.1 Definition

It is an interdisciplinary scientific field that deals with how computers can be made to gain a high-level understanding of digital images or videos. From the perspective of engineering, it seeks to automate tasks that the human visual system can do[56].

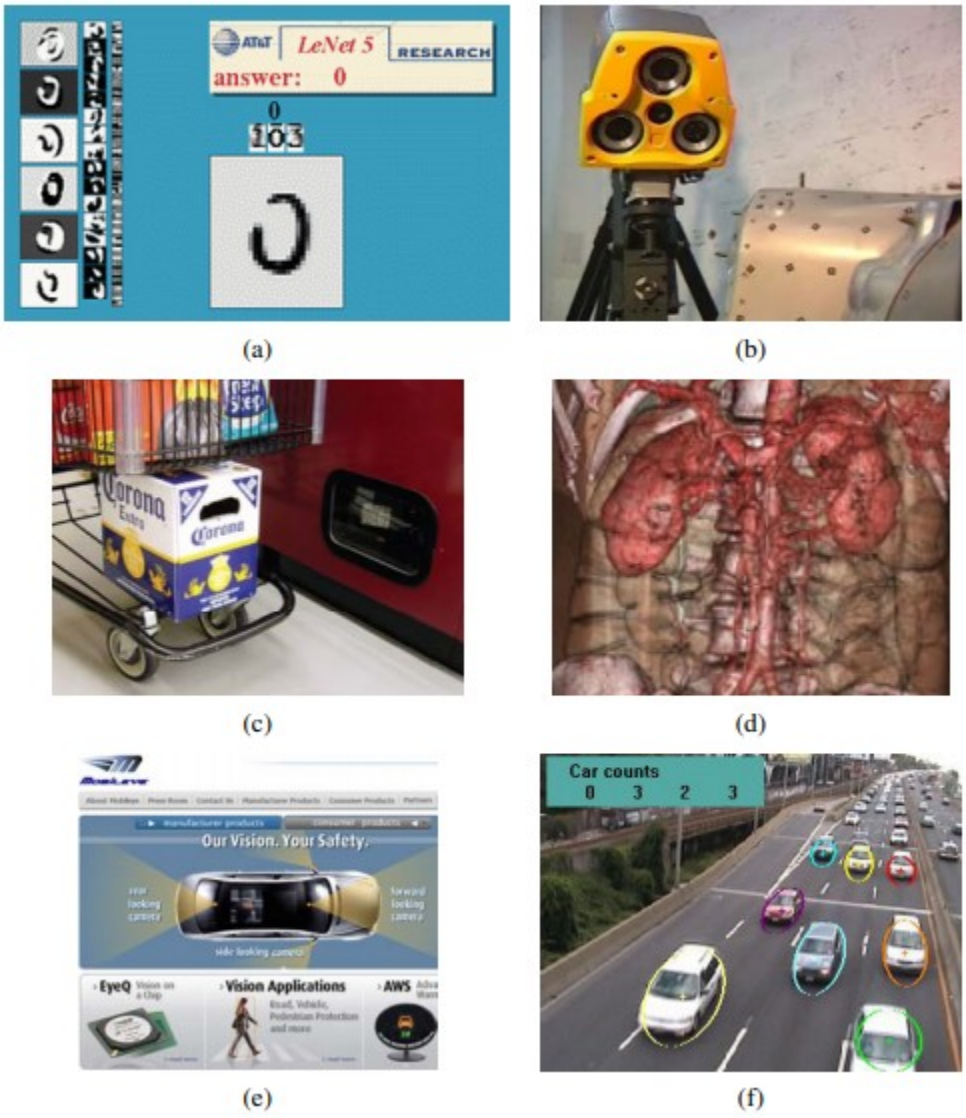
Computer vision tasks include methods for acquiring, processing, analyzing and understanding digital images, and extraction of high-dimensional data from the real world in order to produce numerical or symbolic information, e.g. in the forms of decisions. Understanding in this context means the transformation of visual images (the input of the retina) into descriptions of the world that can interface with other thought processes and elicit appropriate action. This image understanding can be seen as the disentangling of symbolic information from image data using models constructed with the aid of geometry, physics, statistics, and learning theory[56].

Another way to define computer vision is through its applications. Computer vision is building algorithms that can understand the content of images and use it for other applications[54].

computer vision is being used today in a wide variety of real-world applications, which include[57]:

1. Optical character recognition (OCR): reading handwritten postal codes on letters (Figure 1.4a) and automatic number plate recognition (ANPR);
2. Machine inspection: rapid parts inspection for quality assurance using stereo vision with specialized illumination to measure tolerances on aircraft wings or auto body parts (Figure 1.4b) or looking for defects in steel castings using X-ray vision;
3. Retail: object recognition for automated checkout lanes (Figure 1.4c);
4. Medical imaging: registering pre-operative and intra-operative imagery (Figure 1.4d) or performing long-term studies of people’s brain morphology as they age;

5. Automotive safety: detecting unexpected obstacles such as pedestrians on the street, under conditions where active vision techniques such as radar or lidar do not work well (Figure 1.4e;
6. Surveillance: monitoring for intruders, analyzing highway traffic (Figure 1.4f), and monitoring pools for drowning victims;
7. Fingerprint recognition and biometrics: for automatic access authentication as well as forensic applications



(a) (b) (c) (d) (e) (f)

F. Some industrial applications of computer vision: (a) optical character recognition (OCR) (b) mechanical inspection (c) retail (d) medical imaging (e) automotive safety (f) surveillance and traffic monitoring [57]

7.6.2 How computer vision works[55]

1. Acquiring an image: Images, even large sets, can be acquired in real-time through video, photos or 3D technology for analysis.
2. Processing the image: Deep learning models automate much of this process, but the models are often trained by first being fed thousands of labeled or pre-identified images.
3. Understanding the image: The final step is the interpretative step, where an object is identified or classified.

There are many types of computer vision that are used in different ways[55]:

1. Image segmentation partitions an image into multiple regions or pieces to be examined separately.
2. Object detection identifies a specific object in an image. Advanced object detection recognizes many objects in a single image: a football field, an offensive player, a defensive player, a ball and so on. These models use an X, Y coordinate to create a bounding box and identify everything inside the box.
3. Facial recognition is an advanced type of object detection that not only recognizes a human face in an image, but identifies a specific individual.
4. Edge detection is a technique used to identify the outside edge of an object or landscape to better identify what is in the image.
5. Pattern detection is a process of recognizing repeated shapes, colors and other visual indicators in images.
6. Image classification groups images into different categories.
7. Feature matching is a type of pattern detection that matches similarities in images to help classify them.

Simple applications of computer vision may only use one of these techniques, but more advanced users, like computer vision for self-driving cars, rely on multiple techniques to accomplish their goal[55].

1. Embedded systems

It is a controller with a dedicated function within a larger mechanical or electrical system, often with real-time computing constraints. It

is *embedded* as part of a complete device often including hardware and mechanical parts. Embedded systems control many devices in common use today. Ninety-eight percent of all microprocessors manufactured are used in embedded systems[58].

Modern embed ded systems are often based on microcontrollers (i.e. microprocessors with integrated memory and peripheral interfaces), but ordinary microprocessors (using external chips for memory and peripheral interface circuits) are also common, especially in more complex systems. In either case, the processor(s) used may be types ranging from general-purpose to those specialized in a certain class of computations, or even custom designed for the application at hand. A common standard class of dedicated processors is the digital signal processor (DSP)[58].

Advantages of Embedded [59]

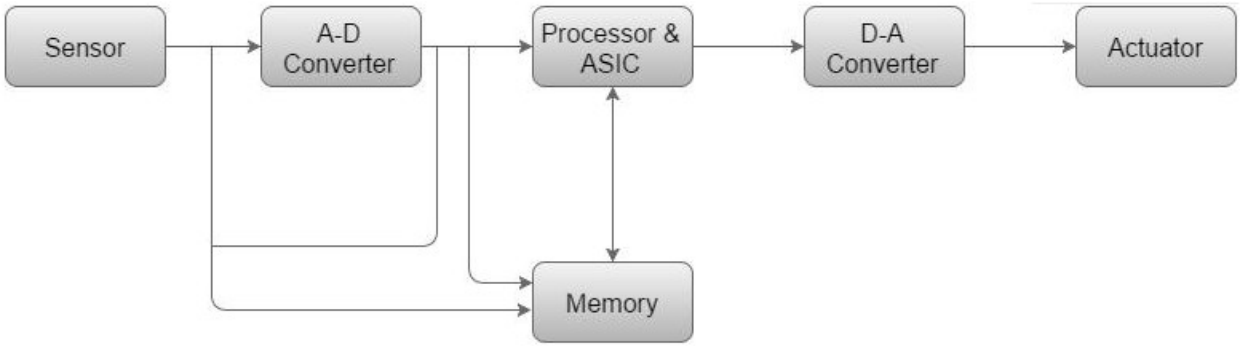
1. Easily Customizable
2. Low power consumption
3. Low cost
4. Enhanced performance

Disadvantages of Embedded systems [59]

1. High development effort
2. Larger time to market
1. Sdfgd

Basic Structure of an Embedded System

The following illustration shows the basic structure of an embedded system.



F. basic structure of an embedded system[59]

2. **Sensor** − It measures the physical quantity and converts it to an electrical signal which can be read by an observer or by any electronic instrument like an A2D converter. A sensor stores the measured quantity to the memory[59].
3. **A-D Converter** − An analog-to-digital converter converts the analog signal sent by the sensor into a digital signal[59].
4. **Processor & ASICs** − Processors process the data to measure the output and store it to the memory[59].
5. **D-A Converter** − A digital-to-analog converter converts the digital data fed by the processor to analog data[59].
6. **Actuator** − An actuator compares the output given by the D-A Converter to the actual (expected) output stored in it and stores the approved output[59].

1. Cybersecurity

7.8.1 Definition

It is the protection of computer sxszazazxaystems from the theft of or damage to their hardware, software, or electronic data, as well as from the disruption or misdirection of the services they provide.

The field is becoming more important due to increased reliance on computer systems, the Internet and wireless network standards such as Bluetooth and Wi-Fi, and due to the growth of "smart" devices, including smartphones, televisions, and the various devices that constitute the "Internet of things". Due to its complexity, both in terms of politics and technology, cybersecurity is also one of the major challenges in the contemporary world[60].

Cybersecurity is often confused with information security but it focuses on protecting computer systems from unauthorized access or being otherwise damaged or made inaccessible. Information security is a broader category that looks to protect all information assets, whether in hard copy or in digital form[61].

The term cybercrime is used to describe an unlawful activity in which computer or computing devices such as smartphones, tablets, Personal Digital Assistants(PDAs), etc. which are stand-alone or a part of a network are used as a tool or/and target of criminal activity. It is often committed by the people of destructive and criminal mindset either for revenge, greed or adventure[62].

Combating this is a multi-disciplinary affair that spans hardware and software through to policy and people – all of it aimed at both preventing

cybercrimes occurring in the first place, or minimizing its impact when it does. This is the practice of cybersecurity[63]

7.8.2 Cybersecurity checklist

Boost your cyber defenses with these must-have security measures[61]:

1. **Staff awareness training:-** Human error is the leading cause of data breaches, so you need to equip staff with the knowledge to deal with the threats they face. Training courses will show staff how security threats affect them and help them apply best-practice advice to real-world situations.

2. **Application security:-** Web application vulnerabilities are a common point of intrusion for cybercriminals. As applications play an increasingly critical role in business, it is vital to focus on web application security.

3. **Network security:-** Network security is the process of protecting the usability and integrity of your network and data. This is achieved by conducting a network penetration test, which scans your network for vulnerabilities and security issues.

4. **Leadership commitment:-** Leadership commitment is the key to cyber resilience. Without it, it is very difficult to establish or enforce effective processes. Top management must be prepared to invest in appropriate cybersecurity resources, such as awareness training.

5. **Password management:-** Almost half of the UK population uses ‘password’, ‘123456’ or ‘qwerty’ as their password. You should implement a password management policy that provides guidance to ensure staff create strong passwords and keep them secure.

7.8.3 Types of cybersecurity threats

1. **Ransomware:-** It is a type of malicious software. It is designed to extort money by blocking access to files or the computer system until the ransom is paid. Paying the ransom does not guarantee that the files will be recovered or the system restored[64].

2. **Malware:-** itis a type of software designed to gain unauthorized access or to cause damage to a computer[64].

3. **Social engineering:-** it is a tactic that adversaries use to trick you into revealing sensitive information. They can solicit a monetary payment or gain access to your confidential data. Social engineering can be combined with any of the threats listed above to make you more likely to click on links, download malware, or trust a malicious source[64].

4. **Phishing:-** it is the practice of sending fraudulent emails that resemble emails from reputable sources. The aim is to steal sensitive data like credit card numbers and login information. It's the most common type of cyber attack. You can help protect yourself through education or a technology solution that filters malicious emails[64].

7.8.4 Benefits of cybersecurity

Benefits of utilizing cybersecurity include [65]:

1. Business protection against malware, ransomware, phishing, and social engineering.
2. Protection for data and networks.
3. Prevention of unauthorized users.
4. Improves recovery time after a breach.
5. Protection for end-users.
6. Improved confidence in the product for both developers and customers.

7.8.5 Cybersecurity vendors

Vendors in cybersecurity fields will typically use endpoint, network and advanced threat protection security as well as data loss prevention. Three commonly known cybersecurity vendors include Cisco, McAfee, and Trend Micro[65].

1. Cisco tends to focus on networks and allows its customers to utilize firewalls, VPNs and advanced malware protection along with supporting email and endpoint security. Cisco also supports real-time malware blocking[65].

2. McAfee makes cybersecurity products for consumers and enterprise users. McAfee supports mobile, enterprise clouds, network, web, and server-based security. Data protection and encryption are also offered[65].

3. Trend Micro is an anti-malware vendor which offers threat protection for mobile, hybrid clouds, SaaS and the IoT. Trend Micro provides users with endpoint, email and web security[65].

    1. Additive manufacturing (3D Printing)

Are “3D printing” and “additive manufacturing” (AM) the same thing? In general, we know that terms stretch over time to include more than just their default meanings. Most of us carry digital entertainment supercomputers around in our pockets and call them “phones”[66].

Whatever the name, new ways of fabricating directly from bytes to stuff are radically changing the what, where, how, and when of making objects. What roles, then, do the two terms “additive manufacturing” and “3D printing” play in describing new ways of making?[66]

Let’s start by considering what the experts have to say[66]:

1. The standards organization ASTM International equates the two terms in their definition: “Additive manufacturing, also known as 3D printing, uses computer-aided design to build objects layer by layer.”
2. Wikipedia says, “today, the precision, repeatability, and material range has increased to the point that 3D printing is considered as industrial production technology, with the name of additive manufacturing.”
3. Author Dave Turbide puts it simply, suggesting that additive manufacturing is “the industrial version of 3D printing”.

7.9.1 3D Printing: It's All About the Printer

When MIT invented binder jet printing in the 1980s, they wrote: “three-dimensional printing is a process under development at MIT for the rapid and flexible production of prototype parts, end-use parts, and tools directly from a CAD model.”[66]

Today our concept of “3D printing” is much broader, but the term is often associated with filament-based plastic printers, which are the pride and joy of

many a hobbyist and self-described maker. But there are also binder jet printers, laser metal 3D printers, as well as glass and clay 3D printers[66].

7.9.2 Additive Manufacturing: A Bytes-to-Parts Supply Chain

“Additive manufacturing” (AM) is a big-picture term more at home in the boardroom than the factory floor or garage. Naturally, AM separates itself from older, subtractive technologies like milling. Otherwise, the term is less about the 3D printer itself, and more about the manufacturing process transformed by 3D printing[66].

What is that transformation? AM changes the way we think about inventory and supply chain, taking parts from the point of manufacture to the point of use[66].

AM is flexible in the time it takes to load a file, from anywhere in the world. It enables customized parts, in volume, and involves stocking raw materials like filament and printing spare parts on demand[66].

additive manufacturing (AM) describes types of advanced manufacturing that are used to create threedimensional structures out of plastics, metals, polymers and other materials that can be sprayed through a nozzle or aggregated in a vat.1 These constructs are added layer by layer in real-time based on digital design. The simplicity and low cost of AM machines, combined with the scope of their potential creations, could profoundly alter global and local economies and affect international security[67].

3D printing (also known as additive manufacturing, AM) is a breakthrough technology that has been developing for more than 30 years but has attracted more and more attention in recent years. The American Society for Testing and Materials (ASTM) International defines AM as “A process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies”. The seven major additive manufacturing processes as classified per ISO (ASTM F42) are material jetting, binder jetting, material extrusion, vat polymerization, powder bed fusion, direct energy deposition, sheet lamination. With the development of 3D printing (3DP) from rapid prototyping to the end-of-use product manufacturing process, manufacturing constraints have been greatly relieved and design freedom has been significantly expanded, including shape complexity, material complexity, hierarchical complexity, and functional complexity. In particular, 3D printing has the unique capability to control the point-line-area in geometry and material of each

layer for an object at full-scale length ranging from micro to macro-scale. The emerging multi-scale and multi-material 3D printing technique possesses great potential to implement the simultaneous and full control of fabricated object which involves the external geometry, internal architecture, functional surface, material composition, and ratio as well as gradient distribution, feature size ranging from nano, micro, to macro-scale, embedded components and electro-circuit, etc. Therefore, it is able to construct the heterogeneous and hierarchical structured object with tailored properties and multiple functionalities that cannot be achieved through the existing technologies. Such technology has been considered as a revolutionary technology and next-generation manufacturing tool which can really fulfill the “creating material” and “creating life”, especially subvert traditional product design and manufacturing scheme. 3D printing paves the pathway and will result in a great breakthrough in various applications, for example, functional tissue and organ, functionally graded material/structure, lattice material/structure, metamaterial, smart material, functionally embedded electronic component, bio-inspired material/ structure, multi-functionality product, soft robot, etc. Furthermore, it may promote tremendous progress in many subjects involving material, bio-medical, electronics, mechanics, bionics, aerospace, etc[68].

In the last few years, 3D printing has been utilized to fabricate electronics and structural electronics. More specifically, electronic/electrical components can be deposited and embedded in a 3D structure to form a multi-functionality product by interrupting the 3D printing process. 3D printing promotes the integrated assemblage and embedded other components as results of layer-by-layer or point-by-point characteristics. Functional elements such as sensors, circuits, and embedded components are now being integrated into 3D-printed products or structures, paving the way for exciting new markets, applications, and opportunities. Furthermore, 3D printing can be harnessed to print electronics on stretchable and flexible bio-compatible “skins” with integrated circuitry that can conform to irregularly-shaped mounting surfaces. Therefore, 3D printing electronics can offer great potential and unique capabilities to build a complex object with multiple functionalities. Particularly, it has shown the unique ability to produce embedded electronics, 3D structural electronics, conformal electronics, stretchable electronics, OLED, etc[68].

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