IJCRT.ORG ISSN : 2320-2882
INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Artificial Intelligence (AI), Internet of Things (IoT) and Machine Learning (ML) in Healthcare- A Way Forward

Prashant*, Vipula , Dr Nitin

School of Medical and Allied Sciences, K.R. Mangalam University, Gurugram

Abstract: The idea of intelligent, independently learning machines have always been a dream for human race. Healthcare generates a vast amount of useful data and The Internet of Things (IoT) makes this feasible and provides a big volume without human intervention. But it is not cost effective to generate and analyse every bit of available data. This is where Machine Learning and Artificial Intelligence (AI) come to rescue. These technological branches of science help in sifting data received from IOT interfaces. Though it seems tempting and achievable, yet combining IOT and AI is tedious. It requires a massive investment and selective expertise. The present review discusses the basics of Artificial Intelligence, Machine Learning and Internet of Things, along with their applications in the field of healthcare.

Introduction:

Artificial Intelligence (AI):

Artificial Intelligence (AI) is the branch of engineering science which deals with creating and implementing intelligent computer programs which make the machines capable of making intelligent decisions during operation. It refers to the ability of a computer or a robotic computer enabled system to process the given information and produce outcomes in a manner similar to the attention process of humans in learning, deciding and solving problems. AI also aims to create intelligent machines, which will become an essential part of the technology industry and research. [1]

AI is one of the most highly anticipated digital healthcare technologies. While the concept of AI should seem futuristic to some, the age of machine learning is already here. Uptake in pharmaceutical industry has been relatively slow compared to others. But in order to stay relevant the industry will need to adapt faster. [2]

AI can play a critical role in health industry, like exploring the unmet medical needs of healthcare sector, meeting the pace with which resistance is being developed for molecules such as anti-tuberculosis, and matching the rate at which new diseases are being identified. The traditional drug discovery approach can take up to 10 to 15 years and about $2.5 billion investment to bring a molecule from conceptual stage to market. AI can help reducing these numbers to a drastic level. [3] [4]

Broadly, AI is defined as computer systems able to perform tasks that normally require human intelligence. It comprises three distinct types: human-created algorithms, machine-learning, and deep learning. [5]

Applications of Artificial Intelligence in Pharma Industry:

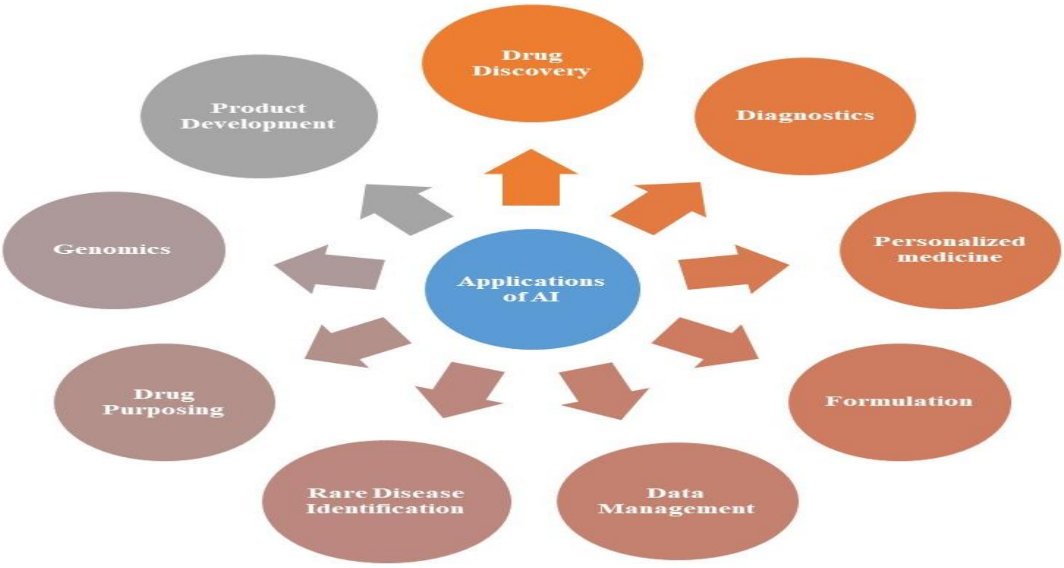

Figure 1: Applications of Artificial Intelligence

1) **Drug Discovery:** AI can play an important role in initial screening of drug compounds, prediction of the success rate of a drug and more specifically, it may play a role in drug target identification and validation, multi-target drug discoveries, drug repurposing, and biomarker identification. Ideally, this would also translate to lower drug costs for patients, all while offering them more treatment choices. Many pharma companies, in collaboration with AI companies, have developed cloud-based AI platforms to accelerate their drug discovery programmes. These platforms look for pattern in data and make use of algorithms that can make accurate predictions about the potential drug molecules based on computational structure analysis, drug target and data from in-vivo cell line studies [1].
For instance, Watson Health and Pfizer announced a collaboration to accelerate Pfizer's immuno-oncology discovery programme using cloud-based Watson's machine-learning system. The IBM Watson platform will aid in identification of new drug targets, fixed-dose combinations to be studied and provide assistance in selecting patients for trials [6].

Similarly, UK-based AI drug discovery company Exscientia signed one of the biggest AI drug discovery deal with Celgene to accelerate its small molecule discovery programme in oncology and autoimmunity segment [7].
In addition to it, Exscientia is also supporting drug discovery programme of Sanofi, GlaxoSmithKline, Sumitomo, Evotec, etc, using its artificial intelligence algorithms [8, 9].

2) **In Formulation:**

a) Controlled release tablets: The first work in the use of neural networks for modelling pharmaceutical formulations was performed by Hussain and co-workers at the University of Cincinnati (OH, USA). In various studies they modelled the in vitro release characteristics of a range of drugs dispersed in matrices prepared from various hydrophilic polymers. In all cases, neural networks with a single hidden layer were found to offer reasonable performance in the prediction of drug release. In general, the results were comparable with those generated through the use of statistical analysis, but when predictions outside the limits of the input data were attempted performance was poor. No attempt was made to optimize the formulations using genetic algorithms, but the results generated did lead the researchers to propose the concept of computer aided formulation design based on neural networks.[10]
In a more recent study involving the formulation of diclofenac sodium from a matrix tablet prepared from cetyl alcohol, personnel from the pharmaceutical company KRKA dd (Smerjeska, Slovenia) and the University of Ljubljana (Slovenia) have used neural networks to predict the rate of drug release and to undertake optimization using two- and three-dimensional response surface analysis. Non-linear relationships were found between the release rate and the amounts of the ingredients used in the formulation, suggesting the possibility of the production of several formulations with the same release profile [8]

b) Immediate release tablets: add this area began only around three years ago with two studies. One by Turkoglu and associates from the University of Marmara (Turkey) and therefore the University of

Cincinnati used both neural networks and statistics to model tablet formulations of hydrochlorothiazide. The networks produced were wont to prepare three-dimensional plots of either massing time, compression pressure and crushing strength, or drug release, massing time and compression pressure in an effort to maximise either tablet strength or to pick the simplest lubricant. Although trends were observed but no optimal formulations got. The trends were like those generated by statistical procedures. Comparable neural network models were generated then optimized using genetic algorithms.it had been found that the optimum formulation trusted the constraints applied to ingredient levels utilized in the formulation and therefore the relative importance placed on the output parameters. A high tablet strength and low friability could only be obtained at the expense of disintegration time.altogether cases lactose was the well-liked diluents and fluidized bed was the well-liked granulating technique [11].[31]

3) **In Product Development:** The pharmaceutical development process may be a multivariate optimization problem. It involves the optimization of formulation and process variables. one among the foremost useful properties of artificial neural networks is their ability to generalize. These features make them suitable for solving problems within the area of optimization of formulations in pharmaceutical development. [12].
Self-learning AI platforms like Artificial Neural Network (ANN) and style of Experiment (DoE) helps in understanding inter-parameter interactions and further supports in composition and process optimisation. It helps in developing a multivariate correlation to get a top quality drug product, supported understanding of cause-effect relationship between formulation ingredients/process parameters and quality target product profile [11].[31]
ANNs provided a useful gizmo for the event of microemulsion-based drug-delivery systems during which experimental effort was minimized. ANNs were used to predict the phase behaviour of quaternary microemulsion-forming systems consisting of oil, water and two surfactants. ANN was also used to simulate aerosol behaviour, with a view to employing this type of methodology in the evaluation and design of pulmonary drug-delivery systems [13].
For controlling and decision-making, symbolic logic may be a very powerful problem-solving technique. It provides very useful rules from input data, in the form of "if… so… then". Fuzzy logic can be combined with neural networks as neuro fuzzy logic. This combination provides more flexibility and capability to the technique and provides powerful results
ANN (Artificial Neural Network) models showed better fitting and predicting abilities in the development of solid dosage forms in investigations of the effects of several factors (such as formulation, compression parameters) on tablet properties (such as dissolution).

4) **In Genomics:** Genomics has developed a platform technology that maps genes which are responsible for causing disease and then maps the drug molecule that target them to provide cure. Currently, the platform is being used to discover molecules for treatment of neurological diseases [3].

Additionally, Broad Institute of MIT and Harvard offering to welcome sequencing, genotyping and expression projects. They currently offer access to the platforms like Human Whole Exome Sequencing, Human Whole Transcriptome Sequencing, Data Analysis etc.
HealNet is one of the largest and complex database systems available for existing drugs for rare diseases. This database is developed by Healx and it contains more than billion documented interactions among patients, existing drug molecules and rare diseases. It uses machine learning and AI to repurpose drug molecules for curing rare diseases. Also, Ligand Express, a cloud-based platform from Cyclica, leverages biophysics and AI to identify drug target, mechanism of action, elucidation of adverse effect and repurposing of small molecules [3][14]

5) **In Personalised medicine:** All individuals are not same with respect to physical structure, rate of metabolism, genetic makeup etc, and therefore the therapy/dose needs to be personalised based on individual requirement. Methods like artificial intelligence and the underlying machine learning can provide the framework to stratify patients, initiate specific tailored treatments and thus increase response rates, reduce adverse effects and medical errors. GNS Healthcare's "Reverse Engineering and Forward Simulation" (REFS), a machine-learning and simulation platform, aids in finding and validating potential new drug candidates based on patient response marker and thus leading to personalised treatments that are better match to individual patients.[15]

6) **In Rare Disease Identification:** Using AI, body scans can detect cancer and other diseases early, as well as predict health issues people might face based on their genetics. Although far from perfect, IBM Watson for Oncology is currently the leader in AI for personalized treatment decisions in the oncology space. It uses each patient's medical information and history to optimize the treatment decision-making. Recently, Watson correctly diagnosed a rare form of leukemia in a patient originally thought to have acute myeloid leukemia. It reportedly examined millions of oncology research papers in 10 minutes after which it successfully diagnosed the patient and recommended a personalized treatment plan. [16]
7) **In Clinical Trial Research**: Tencent Holdings, along with Medopad, has developed AI algorithms for patients suffering from Parkinson's disease. AI monitors patient's movement via smartphone camera and determines the severity of the symptoms. Further, it also permits the doctor to monitor patient remotely, adjust dose and fix doctor's appointment.[17] [18]

8) **In Data Management:** This includes management of medical records. Using a sensor or mobile application like AiCure, a patient's medication use are often monitored in real-time by AI. This could be especially beneficial for patients in whom adherence is an issue and for clinical trials.[19] IoT and its integration with various wearables to have the real time data sent over to a centralised processing centre can help monitor the patients without being physically present.

9) **Betterment in patient care:** Artificial Intelligence is on track to wholly alter the future of healthcare. With the integration of AI into the work of both medical professionals and hospital systems, one can expect to see dramatic changes in both patient health outcomes and in the operational efficiency of hospitals. The "open AI ecosystem" is one among the highest 10 promising technologies in 2016. It is useful to gather and compare the info from social awareness algorithms. In healthcare system vast information is recorded which incorporates patient medical record and treatment data from childhood thereto age. This enormous data can be analysed by the ecosystems and gives suggestions about lifestyle and habits of the patient. [20][21]

Area	**Applications**
Drug discovery	Screening of drug compounds, prediction of the success rate of a drug, drug target identification and validation, multi-target drug discoveries, drug repurposing and biomarker identification.[1][6]
Diagnostics	FDA granted Bayer and Merck & Co with Breakthrough Device Designation for AI pattern recognition software that analyses images from cardiac, lung perfusion and pulmonary vessels [22]. This software will support radiologists by identifying signs of Chronic Thromboembolic Pulmonary Hypertension (CTEPH), a rare form of pulmonary hypertension.
In Formulation	Modelling pharmaceutical formulations. Three-dimensional plots of massing time, compression pressure and crushing strength, or drug release, massing time and compression pressure in an attempt to maximize tablet strength or to select the best lubricant.[8][10][11]
In Product Development	The combination of Self-learning AI platforms like Artificial Neural Network (ANN) and Design of Experiment (DoE) provides more flexibility, powerful results, supports in composition and process optimisation. It helps in developing a quality drug product, as it provides a better clarity between formulation ingredients/process parameters and quality target product profile [12].
In Genomics	verge Genomics has developed a platform technology that maps genes which are responsible for causing disease and then maps the drug molecule that target them to provide cure. Currently, the platform is being used to discover molecules for treatment of neurological diseases [3].
In Drug repurposing	AI helps to match the available data of drug molecules to new targets.[14]

In Personalised medicine	AI can be used to stratify patients, initiate specific tailored treatments and thus increase response rates, reduce adverse effects and medical errors. [15]
In Rare disease identification	Using AI, body scans can be done to detect cancer and other diseases early and as well as predict health issues based on genetics. AI can use a patient's medical information and history to optimize a personalized treatment plan.[16]
IN clinical trial research	AI can monitor a patient's movement via smartphone camera and determine the severity of the symptoms. It can allow a doctor to monitor patient remotely, adjust dose and fix appointment for the patient.[17][18]
In data management	Maintenance of medical records using a sensor or mobile application, beneficial for patients in whom adherence is an issue and for clinical trials.[19]
Betterment in patient care	Artificial Intelligence is on target to wholly alter the longer term of healthcare. With the mixing of AI into the work of both medical professionals and hospital systems, expect to ascertain dramatic changes in both patient health outcomes and within the operational efficiency of hospitals.AI help to people in health care system - The "open AI ecosystem" is one among the highest 10 promising technologies in 2016. It is useful to gather and compare the info from social awareness algorithms. In healthcare system vast information is recorded which incorporates patient medical record and treatment data from childhood thereto age. This enormous data can be analysed by the ecosystems and gives suggestions about lifestyle and habits of the patient.[20][21]

Table1. Summary of Applications

Internet of Things (IoT):

Internet of Things (IoT) has the supremacy to modernize pharmaceutical manufacturing in processes ranging from drug discovery to secluded patient access and monitoring. Numerous top pharma companies from around the gradually adopting IoT technologies in their developed plants to accomplish optimization and improve development efficiency. Earlier, due to different information formats for different methods in a medication manufacturing plant, data access and understanding posed a significant challenge for operative communication. IoT technologies based on various underlying communication protocols for example NFC, Bluetooth, Ultra Wide Band and 5G empower calibration within a pharmaceutical manufacturing plant by meritoriously connecting network, equipment, and schemes across the plant. Moreover, using IoT, pharma companies can gain access to instantaneous data and prominence of operations through the whole manufacturing process.[23]

The Internet of Things (IoT) has a massive effect on many industries universal. But, the pharmaceutical industry has been relatively conservative in implementing technological variation, so the belongings haven't been felt as powerfully across the pharmaceutical and medical industry yet. However, the IoT has unbelievable potential to help pharma and device companies recover superiority output, reduce costs, and even change the way that medication is delivered to the prescribers.

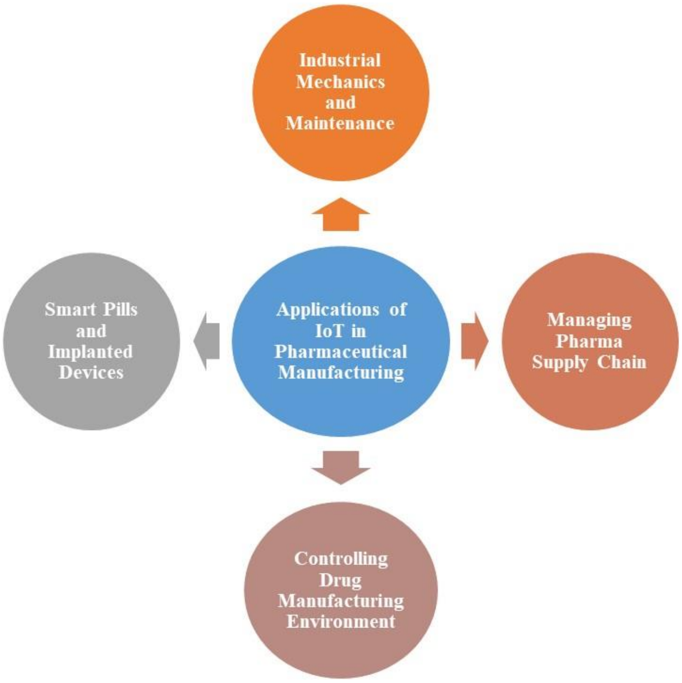

Figure 2: Applications of IoT in Pharmaceutical Manufacturing

1) **Industrial mechanics and maintenance**: Although the use of industrial monitoring devices is already widespread in the pharmaceutical industry, real-time status information is yet to be widely available. Using pharma IoT monitoring sensors, companies can instantaneously feed all relevant facility data into a single dashboard and can alert a supervisor in case of any abnormal conditions or urgent maintenance requirements. IoT in pharmaceutical manufacturing will also enable handling critical conditions remotely.
2) **Managing pharma supply chain:** Once the drugs leave the manufacturing plant, they travel through different modes of transport and may be subject to varying temperatures and weather conditions. Although in most cases care is undertaken to maintain the packages within the prescribed temperatures, chances of variations during transit cannot be completely ruled out. IoT can be helpful in such situations to provide real-time data to manufacturers with improved supply chain visibility. The temperature changes or any damage to the products will be immediately notified to the manufacturers to determine whether the drugs are fit to sell or not.
3) **Controlling drug manufacturing environment:** In pharmaceutical manufacturing, sub-optimal environmental conditions can often prove to be fatal. However, this obstacle can be easily overcome using IoT. Pharma IoT establishes transparency in drug production and storage environment by allowing multiple sensors to monitor environmental indicators such as temperature, humidity, radiation, and light in real time.[24]
4) **Smart Pills and Implanted Devices:** Leading pharmaceutical companies are using smart devices to administer medications and monitor their effect on patients. This includes the delivery of medications or medical monitors in “smart pills.” One use is simply to check whether patients, especially ones with lapses in memory, are taking their medications on schedule. If they miss a dose or consultation, it will give them a prompt reminder on their phone to help get them back on track. If they fall too far behind schedule, it can notify their physician to step in. Smart pills or implanted devices can also detect changes in a patient’s condition. For example; if there is a serious event, such as a hypoglycemic episode, the device can immediately alert a physician or paramedic.

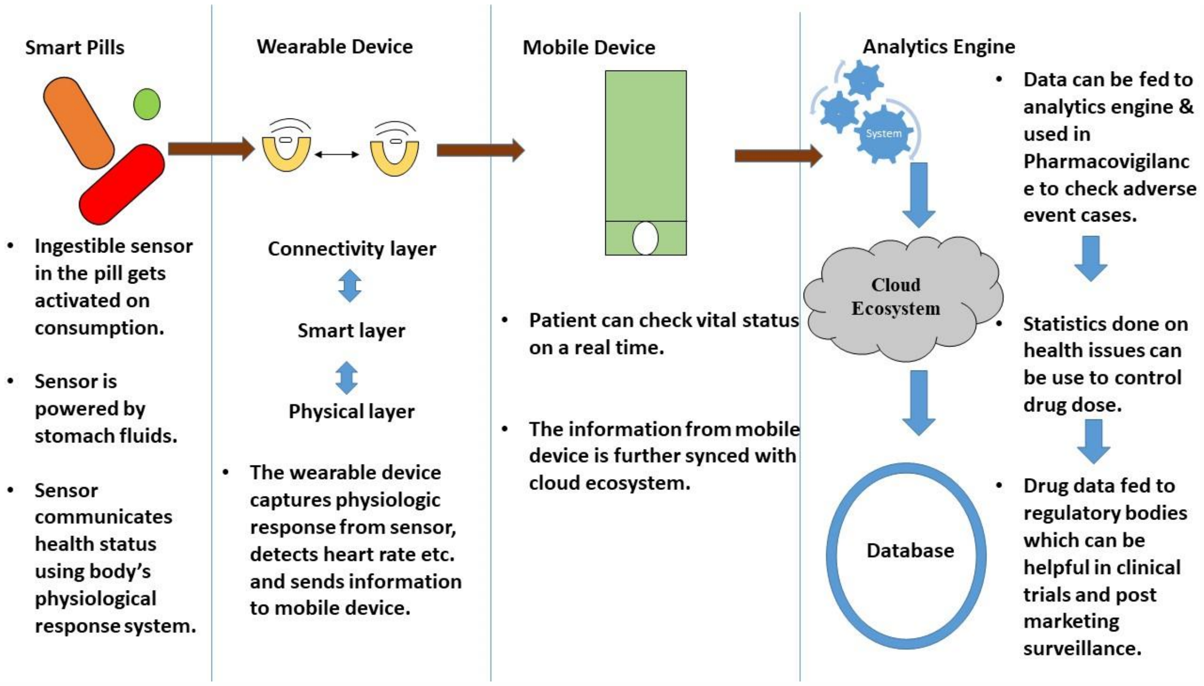

Figure 4: A layout of Smart Pills and Implanted Devices [25]

Internet of Things is a reality in today's era of digitization and, therefore, it deems fit that Pharma companies adopt it at the earliest. Though IOT is still in its nascent stages of development and adoption across industries, it is imperative for Pharma companies to include IOT as part of their strategic focus. This will help them start exploring and implementing IOT applications across value chain components that are ailing and are potential candidates for IOT adoption. This would require companies to take reformative steps such as rehauling systems and processes and transforming business models using nextgen architectures.
On one hand, IoT offers added quality, agility and value to the business; on the other hand, it promises tremendous opportunities for innovation and can lead to a new era of transformation in Pharma.[26]

MACHINE LEARNING

Machine Learning in pharma and medicine could generate a value of up to $100B annually, based on better decision-making, optimized innovation, improved efficiency of research/clinical trials, and new tool creation for physicians, consumers, insurers, and regulators.

Research and development (R&D); physicians and clinics; patients; caregivers; etc. The array of (at present) disparate origins is part of the issue in synchronizing this information and using it to improve healthcare infrastructure and treatments. Hence, the present-day core issue at the intersection of machine learning and healthcare: finding ways to effectively collect and use lots of different types of data for better analysis, prevention, and treatment of individuals.
Burgeoning applications of ML in pharma and medicine are glimmers of a potential future in which synchronicity of data, analysis, and innovation are an everyday reality. We provide a breakdown of several of these pioneering applications, and provide insight into areas for continued innovation.[27]

Figure 3: Applications of Machine Learning in Pharma Sector

No 1 ~ 4 are repeat of usage of AI to ML

1) **Disease Identification/Diagnosis:** Disease identification and diagnosis of ailments is at the forefront of ML research in medicine. According to a 2015 report issued by Pharmaceutical Research and Manufacturers of America, more than 800 medicines and vaccines to treat cancer were in trial. In an interview with Bloomberg Technology, Knight Institute Researcher Jeff Tyner stated that while this is exciting, it also presents the challenge of finding ways to work with all the resulting data. "That is where the idea of a biologist working with information scientists and computationalists is so important," said Tyner. It's no surprise that large players were some of the first to jump on the bandwagon, particularly in high-need areas like cancer identification and treatment. In October 2016, IBM Watson Health announced IBM Watson Genomics, a partnership initiative with Quest Diagnostics, which aims to make strides in precision medicine by integrating cognitive computing and genomic tumour sequencing.
2) **Personalized Treatment/ Behavioural Modification:** Personalized medicine, or more effective treatment based on individual health data paired with predictive analytics, is also a hot research area and closely related to better disease assessment. The domain is presently ruled by supervised learning, which allows physicians to select from more limited sets of diagnoses, for example, or estimate patient risk based on symptoms and genetic information.[28]
3) **Drug Discovery/Manufacturing:** The use of machine learning in preliminary (early-stage) drug discovery has the potential for various uses, from initial screening of drug compounds to predicted success rate based on biological factors. This includes R&D discovery technologies like next-generation sequencing. Precision medicine, which involves identifying mechanisms for "multifactorial" diseases and in turn alternative paths for therapy, seems to be the frontier in this space. Much of this research involves unsupervised learning, which is in large part still confined to identifying patterns in data without predictions (the latter is still in the realm of supervised learning).
4) **Clinical Trial Research:** Machine learning has several useful potential applications in helping shape and direct clinical trial research. Applying advanced predictive analytics in identifying candidates for clinical trials could draw on a much wider range of data than at present, including social media and doctor visits, for example, as well as genetic information when looking to target specific populations; this would result in smaller, quicker, and less expensive trials overall. ML can also be used for remote monitoring and real-time data access for increased safety; for example, monitoring biological and other signals for any sign of harm or death to participants. According to McKinsey, there are many other ML applications for helping increase clinical trial efficiency, including finding best sample sizes for increased efficiency; addressing and adapting to differences in sites for patient recruitment; and using electronic medical records to reduce data errors (duplicate entry, for example).

5) **Radiology and Radiotherapy:** In an October 2016 interview with Stat News, Dr. Ziad Obermeyer, an assistant professor at Harvard Medical School, stated: "In 20 years, radiologists won't exist in anywhere near their current form. They might look more like cyborgs: supervising algorithms reading thousands of studies per minute." Until that day comes, Google's DeepMind Health is working with University College London Hospital (UCLH) to develop machine learning algorithms capable of detecting differences in healthy and cancerous tissues to help improve radiation treatments.[29]
6) **Smart Electronic Health Records:** Document classification (sorting patient queries via email, for example) using support vector machines, and optical character recognition (transforming cursive or other sketched handwriting into digitized characters), are both essential ML-based technologies in helping advance the collection and digitization of electronic health information. MATLAB's ML handwriting recognition technologies and Google's Cloud Vision API for optical character recognition are just two examples of innovations in this area: Artificial Neural Network using MATLAB – Handwritten Character Recognition
The MIT Clinical Machine Learning Group is spearheading the development of next-generation intelligent electronic health records, which will incorporate built-in ML/AI to help with things like diagnostics, clinical decisions, and personalized treatment suggestions. MIT notes on its research site the "need for robust machine learning algorithms that are safe, interpretable, can learn from little labeled training data, understand natural language, and generalize well across medical settings and institutions."
7) **Epidemic Outbreak Prediction:** ML and AI technologies are also being applied to monitoring and predicting epidemic outbreaks around the world, based on data collected from satellites, historical information on the web, real-time social media updates, and other sources. The opioid epidemic is a direct example of AI technology being utalized today. Support vector machines and artificial neural networks have been used, for example, to predict malaria outbreaks, taking into account data such as temperature, average monthly rainfall, total number of positive cases, and other data points.[30]s

Summary: Lower success rate in drug discovery phase with huge speculation of money and time, is one of the most critical reasons for decline in number of NCEs being discovered. In order to conflict these challenges, many pharma companies have already adopted AI in their research programme. Both IoT and AI are powerful and are capable of making your business smarter. And if you combine these two technologies, it will enable enterprises to achieve even greater digital transformation. There are tons of domains that can harvest the advantages of the coexistence of both technologies.

REFERENCE:-

1. Shapiro SC. Artificial intelligence. Encyclopedia of Artificial intelligence, Vol. 1, 2ndedn. New York; Wiley 1992
2. Dasta JF. Application of artificial intelligence to pharmacy and medicine. Hosp Pharm 1992. 27; 312-5:319-22.
3. Computer-calculated compounds. Nic Fleming. Nature, Vol 557, 31 May 2018, S55-S57. https://www.nature.com/magazine-assets/d41586-018-05267-x/d41586-018-05267-x.pdf
4. How artificial intelligence is the future of pharma. Jackie Hunter, BenevolentBio. Drug Target review, 5 December, 2016.
5. Buvailo, A. (2018). How Pharmaceutical And Biotech Companies Go About Applying Artificial Intelligence in R&D. Retrieved from https://www.biopharmatrend.com/post/34-biopharmas-hunt-for-artificial-intelligence-who-does-what/
6. IBM and Pfizer to Accelerate Immuno-oncology Research with Watson for DrugDiscovery. https://www.pfizer.com/news/press-release/press-release-detail/ibm_and_pfizer_to_accelerate_immuno_oncology_research_with_watson_for_drug_discovery
7. AI drug R&D company Exscientia signs deal with Celgene.
8. GlaxoSmithKline signs $43m deal with AI start-up. Rachel Connolly.
9. AI-Based Drug Discovery Biotech is Recruited by Sanofi in €250M Deal.
10. Hayes C., Gedeon T., Hyperbolicity of the fixed point set for the simple genetic Algorithm. Theorical Computer Science, 2010; 411:24-29
11. Goldberg D., Genetic algorithms in search, optimization and machine learning. Addison Wesley.", 1989
12. Man K. F, Tang K. S, Kwong S., Genetic algorithms: concepts and designs, chapter 1-10.

13. 13.Gen M. and Cheng R John, W and Sons Inc.,"Genetic algorithms and engineering design. Artificial intelligence in medicine 1997; 31; 183-196.
14. Artificial Intelligence & the Pharma Industry: What's Next. Codrin Arsene.
15. GNS Healthcare Announces Collaboration to Power Cancer Drug Development with REFS™ Causal Machine Learning and Simulation AI Platform.
16. Faggella, D. (2018). 7 Applications of Machine Learning in Pharma and Medicine. Retrieved from https://www.techemergence.com/machine-learning-in-pharma-medicine/
17. Novatio. (2018). 10 common applications of artificial intelligence in healthcare. Retrieved from https://novatiosolutions.com/10-common-applications-artificial-intelligence-healthcare/
18. Mission Therapeutics and AbbVie sign DUBs Collaboration in Alzheimer's and Parkinson's Disease
19. Siegismund, D., Tolkachev, V., Heyse, S., Sick, B., Duerr, O., Steigele, S. (2018). Developing Deep Learning Applications for Life Science and Pharma Industry. Drug Res (Stuttg), 68, 305–310.
20. AI in Pharmaceuticals. Donna Conroy and Michael Conroy. http://www.pharmexec.com/ai-pharmaceuticals
21. 129 Startups Using Artificial Intelligence in Drug Discovery. Simon Smith. https://blog.benchsci.com/startups-using-artificial-intelligence-in-drug-discovery#step8
22. Melanie M. An introduction to genetic algorithms." A bradford book the MIT press Cambridg, Massachusetts. London, England, 1999, Fifth printing
23. Internet of things retrieved from https://www.businesswire.com/news/home/20190918005548/en/%C2%A0How-IoT-sRevolutionize-Pharmaceutical-Manufacturing-Read-Infiniti%E2%80%99s
24. Industrial mechanics and maintenance , Managing pharma supply chain, Controlling drug manufacturing environment retrieved from https://www.wipro.com/en-AU/pharmaceutical-and-life-sciences/nextgen-pharma-takes-smart-strides-with-internet-of-things/
25. Smart Pills and Implanted Devices retrieved from 2634-ecosystem- leveraging-IoT-architecture-3.jpg
26. https://www.linkedin.com/pulse/top-5-benefits-iot-pharma-industry-how-harness-swapan-kumar-manna/
27. Machine learning, Research and development (R&D) retrieved from https://emerj.com/ai-sector-overviews/machine-learning-in-pharma-medicine/
28. Disease Identification/Diagnosis, Personalized Treatment/ Behavioural Modification retrieved from https://emerj.com/ai-sector-overviews/machine-learning-in-pharma-medicine/
29. Clinical Trial Research, Radiology and Radiotherapy retrieved from https://mindmatters.ai/2018/07/better-medicine-through-machine-learning/
30. Smart Electronic Health Records, Epidemic Outbreak Prediction retrieved from https://exlevents.com/harness-potential-ml-applications-drug-development/
31. Quality by Design Approach: Application of Artificial Intelligence Techniques of Tablets Manufactured by Direct Compression. Buket Aksu corresponding author Anant Paradkar, Marcel de Matas, Özgen Özer, Tamer Güneri, and Peter York. AAPS PharmSciTech. 2012 Dec; 13(4): 1138–1146.