International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-09, Issue-01, Apr 2023

Brain Machine Interface the Paths, Dangers and Strategies of Creating Super humans with Its Dominating Market Analysis

Sumi M, Assistant professor, Department of MCA, Nehru college of Engineering and Research Centre, Thrissur, India, *Sumimurali118@gmail.com*

Vishnu AS, Student Scholar MCA, Nehru College of Engineering and Research Centre, Thrissur, India, *Vishnuofficial18@gmail.com*

Abstract: Recent years have seen an increase in interest in brain-machine interface (BMI) that have been lost, and even the development of superhuman abilities. BMI has great potential advantages, but it also carries some risks, including as the possibility of privacy violations, loss of autonomy, and social injustice. Strict moral standards, openness, and user education are tactics for reducing these hazards. The desire for better healthcare and communication technologies, as well as rising investment in research & development, are projected to fuel the BMI market's growth in the upcoming years. Neuralink, Kernel, and Blackrock Microsystems are major market players. It is crucial to think about the ethical ramifications as BMI technology develops and to make sure that it is designed and applied in a fair and responsible way.

Keywords — Brain computer interface, Electroencephalography, Functional magnetic resonance imaging, Luke arm, Single-Unit Recording, Transcranial magnetic stimulation.

I. INTRODUCTION

The goal of brain-machine interface (BMI) technology, which is quickly developing, is to provide a direct line of communication between the human brain and a computer or other electronic gadget. BMI technology has a wide range of possible advantages, but there are also a number of potential risks to be aware of, including the potential for hacking or other security breaches and moral concerns over the development of "superhumans". Researchers and decision-makers are looking into ways to guarantee the ethical and safe advancement of BMI technology in spite of these worries. The growing demand for applications like prosthetics, virtual reality, and neurological research is likely to propel the market for BMI technology to considerable growth in the upcoming years.

II. BRAIN MACHINE INTERFACE HISTORY

A prosthetic limb or computer can communicate directly with the brain thanks to a technique called a "brain machine interface," or BMI. BMI's origins can be traced to the invention of electroencephalography (EEG), a method for capturing electrical activity in the brain, in the early 20th century.

Researchers started looking into the idea of controlling external equipment like prosthetic limbs with EEG in the 1960s. However, the first effective BMI experiments weren't carried out until the 1990s. Animals' brains were implanted with electrodes for the purpose of these research, and the signals from the implants were used to operate extracellular machinery [1].

Since then, BMI technology has developed quickly, and scientists have created a variety of invasive and non-invasive methods for recording brain waves. With the use of BMI technology, persons with paralysis, neurological diseases, and other ailments can now take control of their body and interact with their surroundings just with their thoughts.

III. ARCHITECTURE OF BRAIN AND THOUGHTS CONTROLLING

All bodily processes, including thoughts and emotions, are managed by the brain, a sophisticated organ. It is made up of various areas, each with a distinct purpose. While the limbic system controls emotions and memories, the cortex is in charge of processing information. The brainstem regulates fundamental processes including breathing and heartbeat.

 DOI : 10.35291/2454-9150.2023.0086

International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-09, Issue-01, Apr 2023

The cognitive functions of the brain—perception, attention, memory, and reasoning—are the source of thoughts. Both electrical and chemical signals are used by neurons to communicate with one another throughout these processes. In order to integrate and process information, neurons work together to build intricate networks [2].

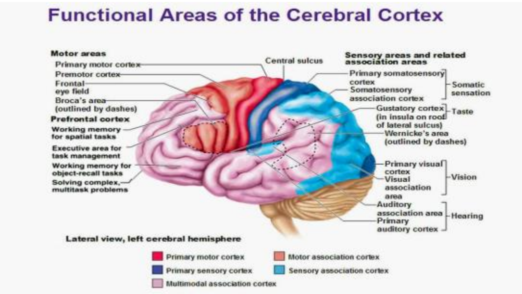

FIG 1: FUNCTIONAL AREAS OF CEREBRAL CORTEX (LATERAL VIEW)

Neurotransmitters, which are molecules that transfer impulses between neurons, are another mechanism by which the brain regulates cognition. Dopamine, for instance, plays a role in motivation and reward, whereas serotonin regulates mood.

Overall, controlling thoughts and managing emotions depends heavily on the structure of the brain and the intricate neurons and neurotransmitters that make up it.

A. CEREBRAL CORTEX SYSTEM AND SUB CORTICAL REGIONS IN BMI

Other brain regions, like the cerebellum and motor cortex, are also addressed by BMI systems in addition to the cerebral cortex and subcortical regions. The cerebellum is involved in the planning and execution of movement and is essential for motor coordination. The cerebral cortex's frontal lobe contains the motor cortex, which is in charge of initiating and regulating voluntary movements.

The performance of BMI systems also depends on their capacity to precisely decode brain signals, which can be influenced by elements like electrode location and neural variability. As a result, current research focuses on enhancing the calibre of neural recordings, creating more sophisticated decoding algorithms, and improving the precision and accuracy of BMI systems [3].

IV.METHODOLOGIES

A. BRAIN IMAGING TECHNOLOGIES IN BMI

Technologies for brain imaging can also be categorized according to how invasive they are. While non-invasive treatments don't require any direct contact with the brain tissue, invasive approaches involve physically accessing the brain tissue. Combining invasive and non-invasive procedures results in minimally invasive procedures. Depending on the kind of signal utilised to interface with the brain, brain-machine interfaces (BMIs) can also be invasive, non-invasive, or minimally invasive.

B. INVASIVE METHODS

To gather data, invasive brain imaging methods directly penetrate the brain tissue. Although quite accurate, these procedures come with a considerable risk of infection and other problems. Examples of invasive procedures include: -Electrocorticography (ECoG), which measures electrical activity by placing electrodes directly on the surface of the brain. Real-time data regarding brain activity can be obtained via ECoG, which is extremely accurate [4].

Deep brain stimulation (DBS) is a technique that modifies brain activity by implanting electrodes deep into the brain. Parkinson's disease, epilepsy, and chronic pain are just a few of the diseases that are treated by DBS.

C. NON - INVASIVE METHODS

Non-invasive methods: Non-invasive methods for brain imaging do not need to come into direct touch with the brain. Although these methods are painless and safe, they might not be as precise as invasive methods. Non-invasive procedures include, for instance:

Non-invasive methods for viewing the structure of the brain include magnetic resonance imaging (MRI) and computed tomography (CT) scans.

Electroencephalography (EEG) measures brain electrical activity by placing electrodes on the head. Epilepsy and other neurological illnesses are frequently diagnosed with EEG, a painless and safe procedure.

A magnetic field is used in Transcranial Magnetic Stimulation (TMS) to stimulate the brain. TMS is a non-invasive method that can be applied to the treatment of disorders like depression.

D. MINIMAL - INVASIVE METHODS

Minimal invasive methods: Minimal invasive methods for brain imaging combine invasive and non-invasive methods. These procedures entail making a small incision or puncture to gain access to the brain tissue. Examples of minimally invasive procedures include as follows:

The method of stereotactic biopsy is used to take a tiny sample of brain tissue for examination. An incision is made in the skull via which the treatment is carried out.

During brain surgery, Neuronavigation employs MRI or CT scans to direct the placement of electrodes or other tools.

The type of signal utilized to interface with the brain determines how invasive, minimally invasive, or non-invasive a brain-machine interface is. For instance:

 DOI : 10.35291/2454-9150.2023.0086

Electrodes are surgically implanted into the brain tissue in invasive BMIs. Although invasive BMIs are very accurate, they come with a considerable risk of infection and other problems.

Non-invasive BMIs employ exterior sensors to find brain impulses. fMRI and the EEG are two examples.

Small sensors or implants are positioned on the surface of the brain during minimally invasive BMIs.

Although they might not be as exact, these gadgets are less dangerous than intrusive BMIs.

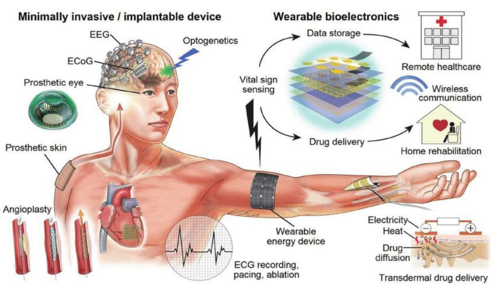

FIG 2: MINIMAL INVASIVE TECHNIQUES WITH IMPLANTABLE DEVICE

E. BRAIN RECORDING TECHNIQUES

The accuracy and dependability of recordings of neural activity in the brain are essential to Brain-Machine Interface (BMI) technology. Here are a few typical methods of brain imaging that are applied in BMI studies:

Electroencephalography (EEG): EEG uses electrodes attached to the scalp to track the electrical activity of the brain. EEG is a common choice for BMI research since it is non-invasive, transportable, and reasonably priced. However, it can be impacted by movement artefacts and has a lesser spatial resolution.

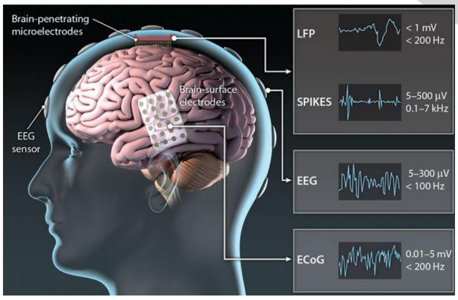

FIG 3: BRAIN RECORDING TECHNIQUES IN BRAIN MACHINE INTERFACE

Placing electrodes directly on the surface of the brain is required for electrocorticography (ECoG). Though more intrusive and requiring surgery than EEG, this method offers superior spatial and temporal resolution.

MEG (magnetoencephalography): MEG analyses the magnetic fields produced by brain electrical activity. Although expensive and requiring specialised equipment, this method offers exceptional spatial and temporal resolution [5].

Using functional magnetic resonance imaging (fMRI), researchers may track variations in blood flow to various brain regions, which may be a sign of neuronal activity. For real-time BMI applications, this approach is unsuitable due to its lower temporal resolution and strong spatial resolution.

V. APPLICATIONS AND RESEARCHES OF BMI

The field of neurology, gaming, and healthcare, robotics, education, entertainment are just a few of the many study fields and applications for brain-machine interfaces (BMIs). This is a thorough summary of some of the primary uses and areas of study for BMIs:

A. PROSTHETICS

BMI technology has the potential to revolutionise the prosthetics industry by giving people with limb loss or dysfunction more control and capability. One of the key advantages of BMI-enabled prostheses is their capacity to provide users more control over their tools, enabling more intricate and delicate movements. Additionally, BMI technology can make prosthetic devices move more naturally, enhancing usability and user happiness. BMI technology can also enhance the user's perception of and response to sensory input, as well as the comfort and fit of the prosthetic device by conveying sensory feedback from the prosthetic device back to the user.

The goal of ongoing research in this field is to increase the prosthesis' accuracy, utility, and acceptance. Improved BMI algorithms that accurately decode cerebral activity and convert it into prosthetic movements are part of this effort. In order to increase the usability and acceptance of these devices, researchers are concentrating on user-centered design methodologies and looking at ways to give sensory feedback from prosthetic devices. Additionally, efforts are being made to regulate prosthetic devices without requiring surgery via non-invasive BMI methods like EEG [6].

In conclusion, BMI technology-based prostheses have the potential to greatly raise the quality of life for people who have lost or dysfunctional limbs. The goal of ongoing research is to create BMI devices that are more precise and user-friendly, provide users more control, and enhance the usability and comfort of prosthetic devices.

B. REHABILITATION

Technology known as the Brain-Machine Interface (BMI) is being investigated as a potential aid for neurorehabilitation. Robotic arms and virtual reality environments can be controlled by BMI systems, which

 DOI : 10.35291/2454-9150.2023.0086

can identify and decode patterns of neural activity in the brain.

BMI systems in neurorehabilitation can give patients an additional means of controlling their limbs and interacting with their surroundings. For instance, patients with spinal cord injuries or strokes may have restricted range of motion or sensation in their limbs, making it challenging to carry out daily chores. Patients can control an external equipment, like a robotic arm, utilising their neurological impulses by applying BMI technology [7].

Moreover, by giving the patient real-time feedback, BMI technology can be employed for motor rehabilitation. For instance, the patient can train themselves to modify their brain activity to better control the external device by seeing their neural signals shown on a computer screen. This feedback loop may encourage brain plasticity and improve recovery from motor injury.

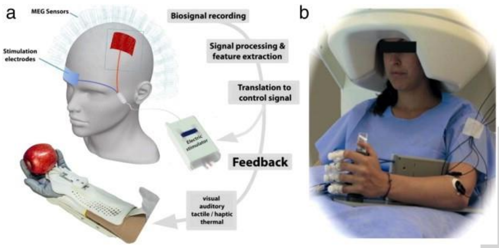

FIG 4: BRAIN MACHINE INTERFACES IN NEUROREHABILITATION OF STROKE

C. COMMUNICATION

Technology called Brain-Machine Interface (BMI) has the power to transform communication for people with severe disabilities or communication problems. BMI systems may identify and decode patterns of neural activity in the brain that can be used to control other devices, including text-based or speech synthesisers. The advantages of BMI technology for communication include giving those with severe disabilities or communication issues an alternative method of expression, quicker and more precise communication, real-time communication, and an improved quality of life. The accuracy, usefulness, and acceptance of BMI systems are being improved by ongoing research in this area, which also examines the use of neural implants, brain-computer interfaces, and user-centered design methods [8].

FIG 5: BRAIN TO BRAIN COMMUNICATION USING BRAIN MACHINE INTERFACE.

D. EDUCATION

Learning with brain-computer interfaces: Scientists are investigating how BMIs can improve learning outcomes by boosting focus and memory. One study showed that transcranial magnetic stimulation (TMS), a non-invasive BMI device, can improve memory consolidation as you sleep.

Neurofeedback is a sort of BMI that gives people feedback about their brain activity in real time, enabling them to learn to manage their own brain activity. It can be used to train attention. With the aid of this technology, ADHD-afflicted kids can learn to pay attention and do better in school [9].

Virtual reality for education and training: VR can offer an immersive learning environment that enables users to hone their abilities in a secure and monitored setting. VR environments can be controlled by BMIs, offering a more comfortable and user-friendly interface for training and learning.

Personalized learning experiences can be provided by using BMIs to continuously monitor and adjust to learners' cognitive states. Learning results for those with cognitive impairments or learning difficulties are being improved because to this technology.

Brain-based evaluations: BMIs are a non-invasive, unbiased technique to evaluate cognitive skills including attention and memory. This technology is being used to create new cognitive function tests and to spot people who could have cognitive or learning difficulties. Overall, BMI research in the field of education is a fast-expanding field with numerous prospective applications and continuing investigations.

E. ENTERTAINMENT

Recent years have seen a substantial increase in interest in the concept of employing brain-machine interfaces (BMIs) for entertainment. Consumer experiences that are immersive and engaging, like virtual reality and gaming software, are one possible advantage. BMIs might potentially open up previously inaccessible types of entertainment for people with impairments, such the ability to mentally control a character in a video game [10].

The field of entertainment-focused BMIs is undergoing continual research, with the goal of creating more effective and precise systems for deciphering brain signals. For instance, scientists have been investigating how deep learning algorithms might be used to analyse neural data and increase BMI accuracy.

Overall, the potential advantages of entertainment-focused BMIs are substantial, but there are also significant privacy, safety, and ethical issues to be taken

 DOI : 10.35291/2454-9150.2023.0086

into account. It will be crucial for researchers and business experts to carefully consider the advantages and hazards connected with employing BMIs for entertainment as technology develops.

FIG 6: GAMING USING BRAIN MACHINE INTERFACE

F. MILITARY

BMIs have been investigated for cognitive enhancement in military personnel, such as enhancing focus, judgement, and reaction speeds. A number of initiatives in this field have received funding from the Defense Advanced Research Projects Agency (DARPA), including the Targeted Neuroplasticity Training program, which uses non-invasive brain stimulation to enhance cognitive function.

Prosthetic limbs that can be controlled by the brain have been used to help injured military troops regain some of their lost mobility. For instance, the Revolutionizing Prosthetics initiative, financed by the Defense Advanced Research Projects Agency (DARPA), has created cutting-edge prosthetic limbs that may be operated by the user's thoughts [11].

BMIs can be used to enhance human-machine teaming, enabling military people to interact with robots like drones and unmanned vehicles more successfully. For instance, University of Pittsburgh researchers have created a BMI system that enables a human operator to command a robotic arm for purposes like bomb disposal.

FIG 7: DARPA SUPER SOLDIER PROJECT.

VI. REAL WORLD PROJECTS AND EXPIRIMENTS

A. LUKE ARM

The Modular Prosthetic Limb (MPL), commonly known as the Luke Arm, is a highly sophisticated prosthetic arm created to help people regain function and mobility after losing an upper limb or limbs due to disease or injury. The undertaking was given the name Luke Skywalker in honour of the famous Star Wars figure who lost his arm in combat and had a robotic arm replaced [12].

The Johns Hopkins University Applied Physics Laboratory (APL), the Department of Veterans Affairs, and the U.S. Army Medical Research and Materiel Command worked together to develop the Luke Arm. The Defense Advanced Research Projects Agency (DARPA) provided funding for the research, which had the objective of developing a prosthetic limb that could replicate the dexterity and range of motion of a normal arm.

The Luke Arm has a modular design that enables users to personalize it to suit their requirements and tastes. It has several joints that enable a variety of motions, such as extension, flexion, and rotation. The user may move and manipulate items with extreme accuracy thanks to a system of sensors that detect their muscle movements and send information to the prosthetic limb.

The Luke Arm's capability to give the user sensory feedback is one of its special qualities. The prosthetic limb is equipped with a number of sensors that can measure vibration, temperature, and pressure. These sensors send signals to the nerves of the user, enabling them to experience feelings and view their surroundings more naturally.

FIG 8: LUKE ARM.

B. IMPROVING VISION IN THE BLIND

By directly activating the brain's visual cortex with electrical signals, brain-machine interfaces (BMIs) have demonstrated potential in enhancing blind people's eyesight. These techniques are intended to provide artificial visual sense to those who have lost their sight as a result of injury or illness by navigating around the

 DOI : 10.35291/2454-9150.2023.0086

ISSN : 2454-9150 Vol-09, Issue-01, Apr 2023

impaired or non-functioning portions of the visual system [13].

One method to accomplish this is to surgically insert a series of electrodes into the visual cortex, which may then be used to transmit electrical impulses that provide artificial visual perception.

In 2017, researchers from Monash University and the University of Melbourne in Australia created a prototype cortical visual prosthesis that could send electrical signals into the visual cortex to stimulate it, enabling blind people to detect patterns of light.

More recently, scientists at UCLA created a minimally invasive cortical visual prosthesis that enabled a blind patient to experience objects and shapes by delivering visual information to their visual brain. This method allowed the patient to get real-time visual information by inserting a small implant into the brain through a tiny hole in the skull [14].

Using optogenetics, a technique that involves genetically altering neurons to make them receptive to light, is an alternative strategy. In this method, light is used to trigger the altered neurons, which can subsequently help the brain produce synthetic visual perception. Although this method is still in its infancy, it has showed promise in animal trials and may one day be used to give blind patients their vision back.

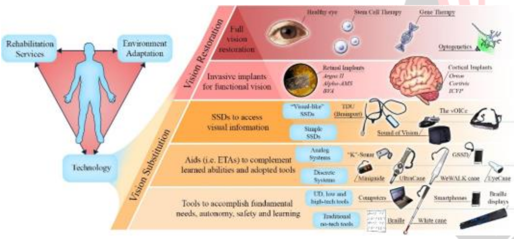

FIG 9. BRAIN MACHINE INTERFACE TO ASSIST THE BLIND.

C. MONKEY OPERATING ROBOTIC ARM

In 2008, University of Pittsburgh researchers created a brain decoder that could foretell a monkey's arm movements in real-time, enabling the monkey to mentally operate a robotic arm. The study was released in the Nature journal [15].

The motor cortex the area of the monkeys' brains responsible for movement—was implanted with two tiny arrays of electrodes by the researchers. As the monkeys moved their arms to reach for a target, the electrodes were utilized to record the electrical activity of specific motor cortex neurons.

After analysing the brain activity, the researchers employed a computer algorithm to instantly forecast the direction and speed of the monkeys' arm motions. With this information, a robotic arm attached to the monkey's chair could be moved in order to reach the target without the monkey having to move its own arm.

The monkeys were able to utilize the robotic arm to reach for targets that were put in various locations around their cage after eventually mastering the ability to manipulate it with their minds. The scientists discovered that the monkeys' accuracy and speed levels were comparable to those of their own arms.

This work showed how neural decoders have the ability to control robotic arms and prosthetic limbs in real time by translating the activity of individual brain neurons. Although there is still more to be done to increase the precision and dependability of these systems, this research marks a significant advancement in the creation of brain-machine interfaces that can give paralyzed or limb-less persons the ability to move and function again [16].

FIG 10. MONKEY OPERATING ROBOTIC ARM (2008).

D. FIRST HUMAN BRAIN TO BRAIN COMMUNICATION

In 2013, a team of researchers from the University of Washington demonstrated the first instance of human brain-to-brain communication with the help of a brain-machine interface (BMI). The research was published in the PLOS ONE journal.

In the experiment, there were two participants—one acted as the sender and the other as the receiver. A computer was attached to the sender's brain, and it was able to distinguish and understand particular patterns of cerebral activity related with the sender's plans to move their hand. The decrypted information was then transmitted through the internet to a computer linked to the receiver's brain via a non-invasive transcranial magnetic stimulation (TMS) technique [17].

Based on the information supplied from the sender, the TMS system was utilized to stimulate particular parts of the receiver's brain that corresponded to the movement of their hand. The sender intended for the recipient to experience a movement in their hand, which they did.

This study showed that BMI technology has the ability to enable direct communication between human brains, and

DOI : 10.35291/2454-9150.2023.0086

it represents a significant advance in the development of more advanced brain-to-brain interfaces that have the potential to be used for a variety of applications, including shared sensory experiences, telepathic communication, and remote control of prosthetic limbs. Although there is still more to be done to increase the precision and dependability of these systems, this discovery marks a significant turning point for the field of brain-machine interfaces.

FIG 11. HUMAN BRAIN TO BRAIN COMMUNICATION INTERFACE.

VII. BRAIN MACHINE INTERFACE CARREERS AND FUTURE SCOPE

Technology known as Brain-Machine Interface (BMI) offers bright future prospects and rewarding job options. BMI technology research and development is a rapidly expanding sector that calls for scientists, engineers, and researchers to create and improve neuroprosthetics, machine learning algorithms, and signal processing algorithms. To use BMI technology in clinical contexts like assistive technology, neuromodulation, and neurorehabilitation, healthcare experts are also required. Additionally, the expanding investment in and interest in BMI technology offers business prospects for those looking to create and market new BMI applications and goods [18].

With ongoing research aimed at enhancing the accuracy, use, and acceptance of these devices, the future of BMI technology seems promising. EEG and other non-invasive BMI procedures may make this technology more widely available and applicable to a larger population. There is an increasing need for experts who can contribute to the development and implementation of BMI technology because it has the potential to revolutionise the way we engage with technology. Consequently, a career in BMI technology can be gratifying and fulfilling and has the potential to improve the lives of others.

VIII. BRAIN MACHINE INTERFACE MARKET ANALYSIS

The Brain-Machine Interface (BMI) market has grown quickly in recent years, and from 2021 to 2028, it is expected to increase at a compound annual growth rate of 11.3%. By 2028, the market is projected to rise to a value of $4.5 billion, propelled by factors including the expansion of the gaming sector and rising demand for BMI technology in the healthcare sector. Neuralink, an organisation started by businessman Elon Musk, now has the biggest market share. Kernel, CTRL-Labs, Emotiv, and G.TEC are further significant players. However, there are a lot of smaller businesses and startups working in the sector, which is very fragmented [19].

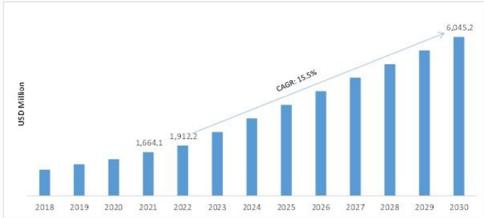

FIG 12. GLOBAL BRAIN MACHINE INTERFACE MARKET

The BMI market is anticipated to increase in the future due to technological advancements and new uses for BMI devices in sectors including healthcare, entertainment, and research. However, the market also faces difficulties including legal restrictions and moral issues that must be resolved for the safe and responsible development and application of BMI technology. Overall, the BMI market is a developing and dynamic industry with tremendous room for expansion and innovation [20].

With the field of Brain-Machine Interface (BMI) technology advancing quickly, the future is tremendously exciting. The creation of non-invasive BMI technology, which might offer a less invasive substitute for the present implantable devices, is one of the main areas of focus. The application of artificial intelligence and machine learning to advance BMI technology, enabling more accurate and precise control of devices utilising brain signals, is another intriguing breakthrough. Additionally, a variety of novel uses for BMI technology are being investigated, including augmented reality and virtual reality experiences. To ensure the secure and efficient use of BMI devices, standardisation and regulation will probably receive more attention as the market expands [21].

IX. OBJECTIVES

Improving human potential: The main goal of producing superhumans is to increase human potential and give people new possibilities to pursue their ambitions.

Enhancing quality of life: Brain-machine interfaces can aid disabled individuals in regaining their independence and enhancing their standard of living.

Technology advancement: Brain-machine interfaces are a quickly developing field that could fundamentally alter how people interact with technology.

Creating novel treatments: Brain-machine interfaces might lead to new remedies for mental and neurological conditions.

 DOI : 10.35291/2454-9150.2023.0086

Improving productivity: By giving workers better tools and increased cognitive abilities, brain-machine interfaces can assist numerous industries, including manufacturing and transportation, become more productive.

Increasing safety: By giving workers better situational awareness and decision-making skills, brain-machine interfaces can increase safety in high-risk professions like mining or firefighting.

Increasing scientific understanding: Brain-machine interfaces can increase scientific understanding by allowing researchers to investigate new fields of study and gain new understanding of how the human body and brain function.

New business opportunities: Companies that can take advantage of the potential advantages of these technologies may gain from the development of brain-machine interface technology.

Ultimately, the goals of developing brain-machine interface-equipped superhumans and advancing present technology are many and have the potential to be extremely beneficial to people, society, and the economy. To make sure that the development of these technologies is done in a responsible and sustainable fashion, these goals must be weighed against potential risks and ethical considerations [22].

X. CONCLUSION

The way people interact with technology and one another may be completely changed by brain-machine interfaces (BMIs). The possibility of developing superhumans appears to be increasing as the field makes progress. However, there are risks related to the creation and application of BMIs, such as potential misuse, privacy issues, and ethical ramifications. The safety and well-being of individuals as well as society as a whole must be balanced with superhuman creation strategies. Regarding the market analysis, BMIs show a developing market with prospective uses in a variety of industries, including communication, gaming, and healthcare. It is anticipated that technology will dominate the technology sector as it continues to advance.

XI. REFERENCES

[1] Frounchi, J., Saeedi, S., Nazeri, M., & Najafabadi, Y. M. (2021). The future of brain-machine interfaces: A review. Journal of biomedical physics & engineering, 11(4), 367-384.

[2] Gu, Y., Angelaki, D. E., & DeAngelis, G. C. (2021). Neural mechanisms of heading perception in primates. Annual Review of Neuroscience, 44, 119-140.

[3] Jafari, M., Haghparast, A., Shamsizadeh, A., & Asadi-Shekaari, M. (2021). Brain-Machine Interfaces and Neuroprosthetics for Recovery of Hand Function in Stroke Patients: A Review. Journal of Medical Signals and Sensors, 11(1), 3-14.

[4] Khushaba, R. N., Kodagoda, S., & Lou, X. (2021). A novel machine learning-based approach for improving the classification of motor imagery EEG signals. Biomedical Signal Processing and Control, 71, 102919.

[5] Liu, M., & Gao, X. (2021). Recent Advances in Brain-Computer Interfaces. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 29, 1753-1758.

[6] Miralles, F., Müller-Putz, G. R., & Miralles, F. (2021). Brain-computer interface: From foundations to state-of-the-art. International Journal of Neural Systems, 31(3), 2130001.

[7] Nikoofard, M., & Oweis, R. (2021). Brain-machine interfaces: a review of principles, recent advances and future prospects. Journal of Medical Engineering & Technology, 45(5), 261-270.

[8] Wang, Q., Wei, X., Guo, J., & Gao, X. (2021). A hybrid EEG-based BCI system for controlling an exoskeleton robot. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 29, 1789-1799.

[9] Wu, Y., & Gao, X. (2021). Recent Advances in Brain-Machine Interface Systems. IEEE Access, 9, 140808-140822.

[10] Yoon, J., Cho, D. W., & Lee, B. (2021). Brain-Machine Interface as a Future Human-Computer Interaction. Journal of Healthcare Engineering, 2021.

[11] Fels, S., Rizzi, G., & Buitrago, M. (2021). Clinical applications of brain-machine interfaces: current state and future prospects. Frontiers in Neuroscience, 15, 629532.

[12] Guo, Y., Liu, S., Chen, X., Li, Y., Li, X., Li, W., & Li, H. (2021). A novel decoding method for real-time finger movement trajectory prediction based on hybrid features and RNN. Journal of Neural Engineering, 18(5), 056019.

[13] He, W., & Chai, X. (2021). Motor Imagery EEG-Based Brain-Computer Interface System with Intention Detection for Smart Wheelchair Control. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 29, 1941-1952.

[14] Kim, H. J., Kim, Y. K., Lee, S. H., & Im, C. H. (2021). Transfer learning-based common spatial pattern for motor imagery classification in patients with amyotrophic lateral sclerosis. Journal of Neural Engineering, 18(6), 066021.

[15] Liu, Y., Yang, L., Zheng, X., & Zhang, D. (2021). A deep learning-based decoding method for non-invasive electroencephalogram signals in a brain-machine interface. Journal of Neural Engineering.

[16] Mahmoudi, B., & Mahmoudi, B. (2021). A Review on the Development of Brain–Machine Interfaces for Patients with Spinal Cord Injuries. Journal of Medical and Biological Engineering, 41(4), 323-334.

[17] Nasirian, M., Foroughi Pour, A., & Gharabaghi, A. (2021). Interfacing Human Brain with Robotic Systems: A Review of State of the Art. Journal of Medical and Biological Engineering, 41(3), 195-205.

[18] Pham, V. T., Lee, S. B., Choi, S., Kim, H. C., & Kwon, O. K. (2021). Neurophysiological correlates of error awareness in a virtual reaching task: A preliminary study. Journal of Neural Engineering, 18(1),

[19] Vázquez-Corral, J., & Morel, P. (2021). Neural Decoding with Inverse Graphics. arXiv preprint arXiv:2105.02371.

[20] Zhang, R., Wang, X., Wang, Y., & Xie, Q. (2021). An EEG-Based Brain-Computer Interface for Handwriting Recognition: Decoding Intention and Motion Dynamics. Frontiers in Neuroscience, 15, 743788.

[21] Nijholt, A., Tan, D. S., & Allison, B. (2020). Brain–computer interfacing for intelligent systems and neuroprostheses: state-of-the-art and future challenges. Frontiers in neuroscience, 14, 601684.

[22] Lebedev, M. A., & Nicolelis, M. A. (2021). Brain–machine interfaces: past, present and future. Trends in Neurosciences, 44(10), 776-793.

 DOI : 10.35291/2454-9150.2023.0086