



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 14, Issue 10, October 2025

A Computer That Can Read Human Thoughts (Brain-Computer Interface)

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ABSTRACT: The concept of computers capable of reading human thoughts is rapidly moving from the realm of science fiction into scientific reality. Advances in neuroscience, artificial intelligence (AI), and signal processing have made it possible to design Brain-Computer Interfaces (BCIs) that can capture and interpret neural activity in real time. These systems create a direct channel of communication between the human brain and external devices, opening exciting opportunities for innovation. This paper explores the scientific principles behind thought-reading technologies, tracing their development from early experiments to modern AI-driven systems. It highlights the methods used to record and decode brain signals, as well as the applications of BCIs in areas such as healthcare, rehabilitation, communication, robotics, and daily human-machine interaction. At the same time, the discussion considers the technical limitations, accessibility issues, and reliability challenges that must be addressed before these systems can be widely adopted. Equally important are the ethical and privacy concerns raised by the ability to decode human thoughts. Questions surrounding consent, autonomy, and the right to mental privacy form a critical part of this emerging field. Finally, the paper reflects on the future scope of BCIs, including possibilities such as direct brain-to-brain communication, memory enhancement, medical breakthroughs, and seamless integration with everyday technology. By offering a comprehensive overview, this work aims to provide readers with a balanced understanding of both the transformative potential and the responsible challenges associated with thought-reading computers.

KEYWORDS: Brain-Computer Interface (BCI), Thought decoding, Neural signal processing, EEG/MEG/fMRI, Intra cortical microelectrodes, Deep learning for BCIs.

I. INTRODUCTION

The human brain is the most complex organ and produces billions of electrical signals every second. For centuries, scientists have tried to decode how thoughts are formed and transmitted. The idea of machines reading human thoughts may sound futuristic, but recent advances in brain mapping and machine learning have made this possibility more realistic. Brain-Computer Interfaces (BCIs) are systems that create a direct communication channel between the human brain and external devices. Rather than relying on speech, gestures, or physical input devices, BCIs bypass muscles and nerves and directly interpret brain signals into machine commands. Companies such as Neuralink, founded by Elon Musk, and research institutions worldwide are developing BCIs that can help restore mobility for paralyzed individuals, enable silent communication, and provide cognitive improvements.

This paper discusses the history, technological principles, applications, challenges, and future perspectives of computers that can read human thoughts.

II. LITERATURE REVIEW

Early Experiments: The scientific exploration of brain activity began in 1924, when German psychiatrist Hans Berger successfully recorded the first electroencephalogram (EEG). His pioneering work revealed that the brain generates measurable electrical signals, now known as brain waves or neural oscillations. At the time, the technology was limited, but Berger's discovery established a foundation for studying how patterns of electrical activity are linked to mental states, thoughts, and behaviours. This breakthrough marked the first step toward connecting human cognition with measurable data.

Brain-Computer Interface Development: The concept of a Brain-Computer Interface (BCI) emerged in the 1970s, when researchers began exploring ways to create direct communication pathways between the human brain and external machines. Early experiments were simple and primarily focused on medical applications, such as helping patients with severe motor disabilities regain some control over their environment. These systems often relied on detecting basic brain signals to perform limited tasks. Over the following decades, advancements in signal processing, computational models, and machine learning techniques significantly improved accuracy. Gradually, BCIs moved beyond experimental setups into real-world applications, opening possibilities in rehabilitation, prosthetics, and assistive technologies.

Modern Research: Today, BCI research is advancing rapidly, driven largely by the integration of artificial intelligence (AI). Sophisticated algorithms, particularly neural networks, can decode highly complex patterns of brain activity. These systems are capable of predicting not only physical actions, such as imagined movements, but also higher-level processes, including speech, emotions, and even visual images perceived by the brain. Major projects highlight this progress: for instance, Facebook's "Silent Speech Interface" aims to convert neural activity into text without spoken words, while DARPA is developing advanced neural decoding systems for both medical and defence applications. Such initiatives demonstrate how far the field has come since Berger's early EEG and hint at a future where direct brain-to-computer communication may become a part of everyday life.

III. WORKING PRINCIPLE OF HUMAN-BRAIN INTERFACES

Neural Signals: The brain has billions of neurons that communicate through electrical impulses called action potentials. These signals create measurable patterns when groups of neurons fire together. BCIs aim to capture and decode these patterns.

3.1 EEG (Electroencephalography)

EEG is a safe and painless method to study brain activity by placing small wires (electrodes) on the scalp. These electrodes pick up electrical signals produced by the brain when we think, move, or sleep. It's often used to check for issues like epilepsy or sleep disorders. EEG shows brain activity quickly and in real-time, but it can't pinpoint exactly where in the brain the signals originate. Still, it remains a popular and low-cost method used in hospitals and lab

3.2 MEG (Magnetoencephalography)

MEG reads the tiny magnetic fields generated by the brain when neurons are active. It offers more detail than EEG, specifying which part of the brain is engaged during speech, movement, or thinking. Doctors use MEG before brain surgeries to avoid damaging critical areas. While very accurate and fast, MEG machines are expensive and require special rooms, so they are typically employed in large hospitals or research centers.

3.3 fMRI (Functional MRI)

fMRI is a large scanning machine that shows which part of the brain is active by measuring blood flow. When we think or act, certain brain regions require more oxygen, and fMRI tracks this need. It provides very clear images of the brain, pinpointing where activity occurs. However, fMRI has a slower response time compared to EEG or MEG. Researchers often use it to study memory, emotions, and brain functions.

3.4 Implantable Electrodes (Invasive)

Implantable electrodes are tiny wires inserted directly into the brain through surgery. They read brain signals with high accuracy because they are close to the neurons. This method is used in serious medical situations or in advanced

experiments like Neuralink, where individuals can control devices through thought. It assists people with paralysis or severe brain injuries. However, surgery carries risks like infection, so it is used only when absolutely necessary.

3.4.1 Signal Processing

Once signals are recorded, noise reduction techniques filter out irrelevant brain activity. Advanced algorithms extract important features such as frequency, amplitude, and timing of brain waves.

3.4.2 Machine Learning in Thought Decoding

Artificial Intelligence plays a key role. Algorithms are trained to recognize patterns that correspond to specific intentions (for example, moving a hand or thinking of a word). Neural networks and deep learning models ensure high accuracy in linking brain activity to commands.

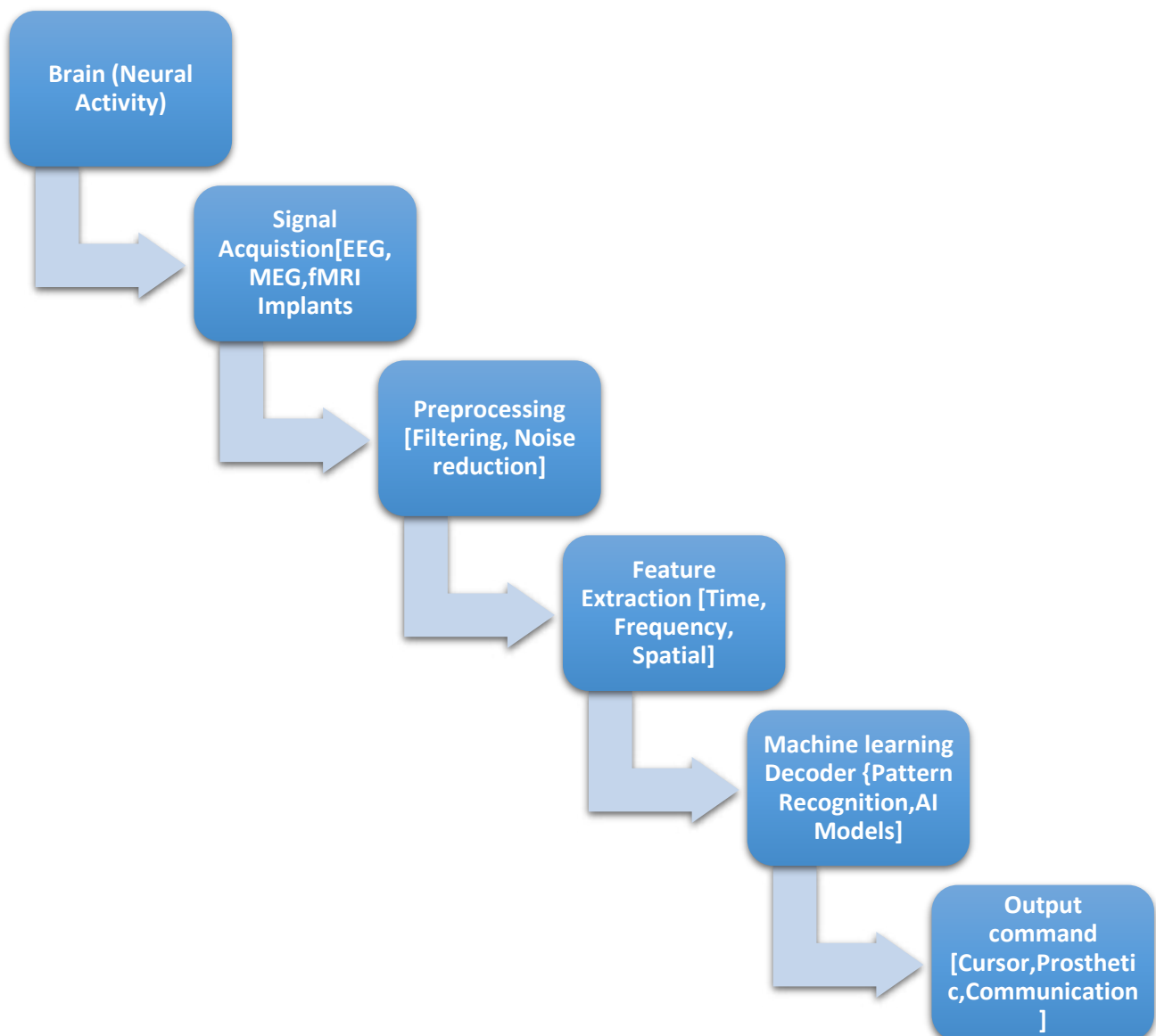


Figure 1. Working Principle of BCIs

IV. APPLICATIONS OF THOUGHT-READING COMPUTERS

4.1 Healthcare

Brain-computer interfaces (BCIs) are empowering patients who cannot move or speak to communicate using just their thoughts. They also allow individuals to control artificial limbs with their minds, which is life-changing for amputees. BCIs can monitor brain activity to detect disorders like epilepsy or Alzheimer's early. Early detection enables doctors to start treatment sooner and manage symptoms more effectively. These technologies bring hope and independence to people facing severe neurological or physical challenges.

4.2 Education

BCIs can help students with disabilities engage with computers using their brain signals. Mind-controlled writing tools enable students to take notes or complete assignments even if they cannot use their hands. This makes learning more accessible and inclusive. Such technologies also help teachers better understand students' needs. Overall, BCIs create a more equal and supportive learning environment for students facing challenges.

4.3 Entertainment and Virtual Reality

In gaming, BCIs allow players to control actions with their thoughts instead of a keyboard or controller. VR systems can respond to a player's emotions, enhancing immersion and realism. This fosters a stronger connection between the player and the game. Such technologies make entertainment more interactive and engaging, opening new possibilities for gaming and virtual experiences in exciting ways.

4.5 Military and Defence

BCIs are being investigated to enable soldiers to communicate silently through thought, reducing reliance on radios or spoken commands. Soldiers may control drones or robotic systems using their brain signals, improving efficiency and safety. This technology allows quicker reactions in dangerous situations and aids in stealth operations. It adds a new level of precision and coordination to military activities. BCIs are gradually changing how defence operations are carried out.

4.6 Robotics and Automation

BCIs can let workers control industrial robots and machines directly with their thoughts. This enhances efficiency, reduces manual effort, and allows people with disabilities to work in technical settings. Human-machine collaboration becomes smoother, as robots can quickly respond to human intentions. These systems are revolutionizing how we work in factories and labs, making automation smarter and more adaptable to human needs.

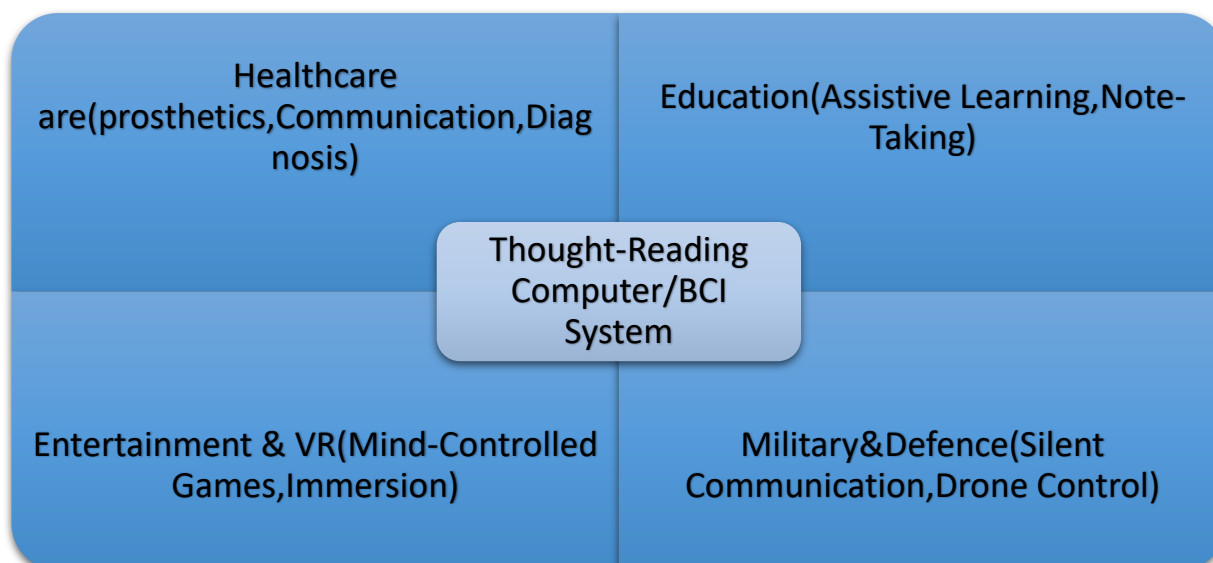


Figure 2. Applications of Thought-Reading Computers

V. CHALLENGES OF THOUGHT-READING COMPUTERS

5.1 Technical Difficulties

The human brain is an extremely complex organ, producing billions of signals every second. These signals often overlap, making it difficult to separate useful information from background noise. Non-invasive techniques such as EEG can record brain activity safely, but the resolution is limited. More precise methods like implanted electrodes provide better data but involve surgery, which carries medical risks. Even with advanced algorithms, accuracy remains imperfect, and misinterpretations are common.

5.2 Cost and Accessibility

Developing and operating brain-computer interface (BCI) systems is still expensive. Machines like fMRI scanners or implantable devices require highly specialised equipment and skilled personnel, which restricts their use to research laboratories or advanced hospitals. For thought-reading technologies to become mainstream, they need to be portable, affordable, and easy to use. At present, the high cost and technical demands prevent widespread adoption, creating a gap between potential and practical availability.

5.3 Reliability Concerns

Unlike fingerprints or voices, brain activity patterns vary widely from person to person. What works for one user may not work for another. Even within the same individual, mental state, stress, or fatigue can influence brain signals. This inconsistency makes it difficult to design systems that are universally reliable. Until these variations are better understood, large-scale application of thought-reading computers will remain limited.

VI. ETHICAL AND PRIVACY CONCERNS

The ability to decode thoughts raises profound ethical questions.

- **Privacy:** Unauthorized access to brain data could be more intrusive than any existing form of surveillance, exposing the most private aspects of a person's life.
- **Consent:** Users should have complete control over which thoughts are monitored and when. Without informed consent, the technology could become a tool of coercion.
- **Human Rights:** Freedom of thought is a fundamental right. If machines can access or influence mental processes, this boundary may be threatened.
- **Responsible Use:** While BCIs can greatly benefit patients with communication or movement disorders, the same technology could be misused for commercial exploitation, surveillance, or manipulation.

VII. SCIENTIFIC FOUNDATIONS

7.1 Brain Signals

Neurons, the basic units of the brain, communicate through small bursts of electricity. Modern techniques allow these signals to be recorded in different ways. Electroencephalography (EEG) collects electrical activity from the scalp, functional magnetic resonance imaging (fMRI) maps blood flow linked to brain activity, and invasive implants provide the most accurate readings by recording directly from the brain's surface.

7.2 Neural Decoding

Once collected, these signals must be interpreted. Researchers use computational methods to identify patterns that correspond to specific actions or thoughts. For example, imagining a hand movement, recalling a word, or recognising a face all produce distinct patterns of brain activity. By mapping these patterns, it becomes possible to predict or "decode" what the brain is trying to do.

7.3 Role of Artificial Intelligence

Artificial intelligence is central to this decoding process. Machine learning algorithms are trained on large datasets of brain activity and linked behaviours. Over time, the system learns to associate a particular neural pattern with an action, word, or image. Some models can even reconstruct speech or predict intended movements from brain signals alone. These advances open new possibilities in assistive technology, such as enabling paralysed patients to communicate or control devices using only their thoughts. However, accuracy, fairness, and safety remain ongoing challenges.

SCIENTIFIC FOUNDATIONS

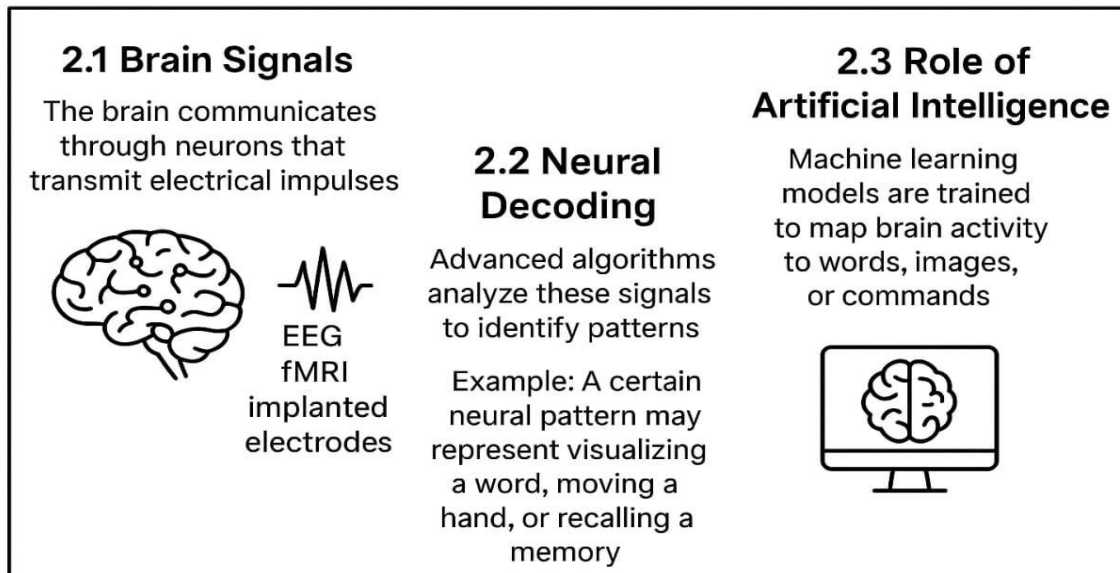


Figure3. Scientific Foundations

VIII. FUTURE SCOPE

8.1 Direct Brain-to-Brain Communication

A major possibility lies in enabling people to communicate directly from one brain to another, bypassing speech or writing altogether. This could revolutionize how humans share ideas, emotions, and experiences. Instead of relying on words, complex concepts might be exchanged instantly, leading to a new dimension of human interaction. While still experimental, early research in transmitting simple signals between brains shows that such communication may one day become reality.

8.2 Memory Enhancement

Thought-reading computers may eventually serve as external memory systems. Just as we store files on a computer, BCIs could one day allow us to record experiences, store knowledge, or retrieve forgotten details with precision. This might help individuals with memory disorders such as Alzheimer's, while also offering healthy users the ability to recall information effortlessly. The ethical challenge, however, will be to ensure that memory enhancement does not lead to manipulation or loss of personal autonomy.

8.3 AI Integration

As AI systems grow more sophisticated, they could merge seamlessly with BCIs to support decision-making and daily life. An integrated AI could anticipate needs, suggest solutions, or even predict risks before a person becomes aware of them. For example, it could warn a driver of fatigue or help a student recall information during a test. Such integration has the potential to extend human capabilities but also raises concerns about dependence on machines for cognitive processes.

8.4 Medical Miracles

One of the most inspiring directions for this technology is in healthcare. BCIs could restore lost senses or abilities, such as giving sight to the visually impaired by connecting directly to the visual cortex, or helping non-verbal individuals speak through thought-to-speech systems. Patients with paralysis might regain mobility by controlling robotic limbs with their minds. These advances would not only improve quality of life but also redefine what is possible in modern medicine.

8.5 Everyday Use

Beyond laboratories and hospitals, thought-reading systems may eventually become part of daily living. Imagine operating smartphones, computers, or even household appliances with a simple thought. This would reduce the need for physical interaction with devices, making technology more accessible for everyone, including people with disabilities. Over time, such convenience could transform how humans interact with machines, much like how touchscreens once replaced buttons.

IX. RESULT AND DISCUSSION

Distribution of BCI Applications in Research & Development

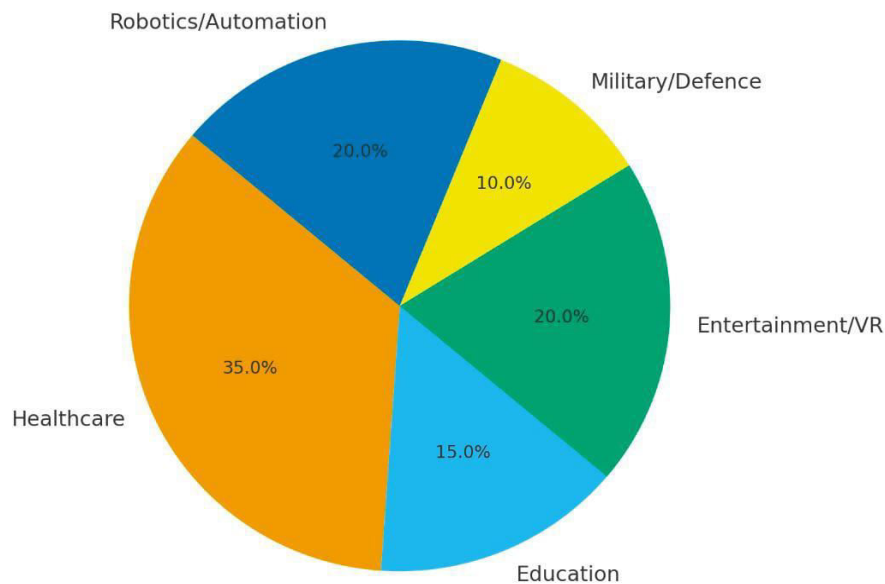


Figure 4. Distribution of BCI Applications in Research & Development

The pie chart provides a visual representation of how research and development in Brain Computer Interfaces (BCIs) are currently distributed across different domains. Each segment of the chart reflects a field where BCIs are making meaningful progress, and together they show how this technology is moving beyond the lab into real-world applications. The largest share, healthcare (35%), highlights the life-changing role BCIs are already beginning to play in medicine. For individuals who have lost the ability to move or speak, these systems create an entirely new way of interacting with the world. Thought-controlled wheelchairs, robotic prosthetics, and communication devices give back independence to people affected by paralysis, spinal cord injuries, or neurodegenerative diseases. In addition, BCIs can monitor brain activity in real time, enabling the early detection of disorders such as epilepsy, Alzheimer's, and Parkinson's. This makes healthcare the leading sector for BCI adoption, as the benefits extend not only to patients but also to doctors, therapists, and caregivers. The next two sectors entertainment and virtual reality (20%) and robotics and automation (20%) are almost equal in their share, and both represent exciting areas of innovation. In entertainment, BCIs are transforming how people experience digital media. Imagine a video game that reacts not to the buttons you press but to your emotions and intentions. Players can control characters with their thoughts, while virtual reality headsets could adapt scenarios based on the user's mental state making the experience more immersive than ever before. Beyond gaming, these same systems could be used in virtual classrooms, art creation, and even mental health therapies, where environments can be tailored to reduce stress or improve focus. In robotics and automation, BCIs are revolutionising the way humans interact with machines. Workers in technical fields could operate complex systems using thought commands, reducing the time and effort needed for manual control. Prosthetics connected to BCIs are becoming increasingly advanced, enabling amputees to perform delicate tasks like grasping objects or even playing

musical instruments. On a larger scale, thought-controlled robots could support industrial work, laboratory automation, or even hazardous tasks in environments unsafe for humans. This blending of the human mind with mechanical precision shows how BCIs can extend human capability well beyond physical limitations. Education (15%) is another emerging sector, where the promise of BCIs is especially strong for inclusivity. Students with disabilities often face barriers to communication and participation in traditional classrooms. BCIs help bridge this gap by allowing students to type, draw, or interact with learning software using only their thoughts. At the same time, teachers and researchers are exploring how BCIs can provide real-time insights into student engagement, focus, and understanding. Such applications could lead to personalised learning systems that adapt to each learner's pace, helping students achieve their full potential. While education holds a smaller share compared to healthcare or entertainment, its impact on accessibility and equity in learning is profound. The smallest portion, military and defence (10%), reflects highly specialised but impactful work. Defence organisations are exploring BCIs for silent communication, enabling soldiers to coordinate without speaking or using devices that could give away their position. Thought-based control of drones, vehicles, or robotic systems is also being tested, aiming to increase reaction speed and precision in critical operations. Although less visible to the public, this field demonstrates how BCIs could reshape strategy and safety in defence activities. Taken together, the chart suggests that BCIs are not a single purpose technology but a multi dimensional tool with applications that touch almost every part of human life. Healthcare dominates for now because of its clear and immediate benefits, but as costs fall and technology improves, sectors like education, robotics, and entertainment will continue to grow. What unites all these areas is the promise of direct human machine communication where intention itself becomes the command. This shift could one day make interacting with technology as natural as thinking itself.

X. CONCLUSION

The prospect of a computer capable of reading human thoughts is one of the most fascinating and, at the same time, one of the most debated frontiers of modern science. On the one hand, thought-reading technologies promise life-changing applications in fields such as healthcare, communication, assistive robotics, and human machine interaction. They could enable paralysed individuals to regain mobility, allow patients with speech impairments to communicate, and even create new ways for humans to interact with technology more seamlessly than ever before. On the other hand, this progress does not come without significant challenges. The technical hurdles including accuracy, cost, and reliability still limit large-scale implementation. More importantly, the ethical, legal, and privacy concerns surrounding the decoding of human thoughts demand careful attention. The possibility of “mind hacking” or unauthorized access to private neural data raises serious questions about autonomy, freedom of thought, and human rights in the digital age. Therefore, the future of thought-reading computers depends on striking the right balance between innovation and responsibility. Continued research must not only focus on advancing the technical capabilities of Brain Computer Interfaces but also ensure that strong safeguards are in place to protect individual privacy and consent. If this balance is achieved, thought-reading systems may well become one of the defining technologies of the 21st century reshaping how humans interact with machines, with each other, and with the world around them.

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