iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** VII **Month of publication:** July 2021

DOI: https://doi.org/10.22214/ijraset.2021.36223

www.ijraset.com

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VII July 2021- Available at www.ijraset.com

AI and Robotics to Rehabilitate Lower Body Paralysis

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Abstract: ***Spinal cord injuries have unpredictable outcomes. While some recover full movement, most of them suffer permanent paralysis, ranging from partial to full-body. Alongside paralysis often comes the loss of bladder control, sexual dysfunction, bedsores, and psychological state issues, among other challenges. The solution for this is the Exoskeleton and the AI technology that offers opportunities to expand virtual and physical access for individuals with disabilities. We will disclose some machines that have an excellent impact on the lives of the elderly and other people with disabilities. However, a very important part of bringing these opportunities to success is guaranteeing that approaching AI technology works well for individuals with a large variety of skills. This paper shows how a wearable exoskeleton suit helps paralyzed people regain their ability to walk, how it works, and how this technology can be improved.***

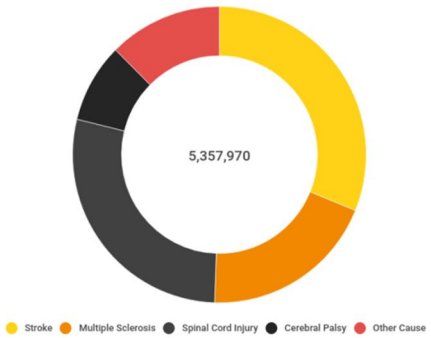
Keywords: Artificial Intelligence (AI), lower-body paralysis, exoskeleton, robotics, EEG

I. INTRODUCTION

According to the prevalence of paralysis across the U.S., nearly 1 in 50 people are living with paralysis – approximately 5.4 million people. That's the same number of individuals because of the combined populations of LA, Philadelphia, and Washington D.C [7].
Paralysis is dramatically more widespread than previously thought. Approximately 1.7 percent of the U.S. population i.e. 5,357,970 people, reported they were living with some sort of paralysis, defined by the study as a central nervous system disorder leading to difficulty or inability to move the upper or lower extremities. The leading reason behind paralysis was stroke (33.7 percent), followed by neural structure injury (27.3 percent) and disseminated sclerosis (18.6)

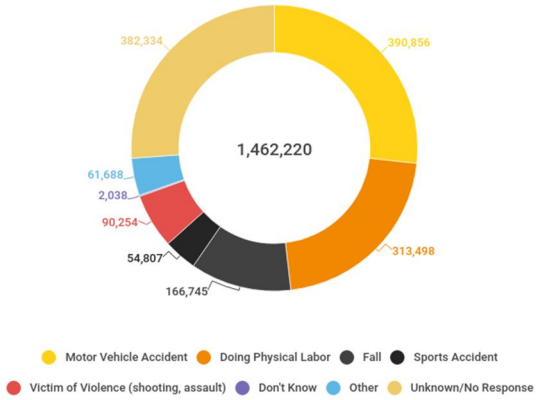
II. LITERATURE REVIEW

Roughly $40.5 billion is the annual cost of Spinal cord injuries -- a 317 percent increase from costs estimated in 1998 ($9.7 billion).
Lower body paralysis is a condition affecting over 65 million people worldwide, as estimated by the world health organization (WHO) for people requiring wheelchairs [1]. Although wheelchairs provide a solution for the population of lower-limb paralyzed people, it creates significant drawbacks for them as well. First, physically limits the person's reach by setting a lower posture. Herewith, changing the way of interacting with the environment, as most objects in our world are designed for a standing living, constrains daily living activities (ADLs) that a person could
Perform. Moreover, socially, it makes a difference with others by forcing people to live seated, seeing, and being seen at a lower perspective than anyone else. This effect on the socio-psychological level has been demonstrated, showing as well that it could be mitigated for lower-limb paralyzed people by the positive effect of standing.
Percent) [7]



Cause of Paralysis

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Causes of Spinal Cord Injuries

III. WHAT IS AN EXOSKELETON?

An exoskeleton is an external frame that will be worn to support the body, either **to serve an** individual to overcome an injury or to boost their biological capacities. Powered by a system of electrical motors, the frame gives limbs extra movement, strength, and endurance.

The lower extremity exoskeleton robot, a special artificial limb, which enwraps the lower limbs of the physical body, is an integrated application of the exoskeleton robots in lower artificial limbs. Since the late 1960s, many scholars have researched when the first active exoskeleton was developed and are still researching this area. Berkeley lower extremity exoskeleton of the University of California, Berkeley [2]. Some of them have already been successfully applied to clinical gait correction to help in walking. Thus, it is recognized that robot-assisted rehabilitation is becoming increasingly common in patients after stroke.

All of the currently available commercial systems have different design specifications in terms of overall configuration, weight, battery life, cost, adjustability, and functionality, but the overall aim of each system is to enable individuals who have been paralyzed by neurological dysfunction to stand up and walk.

The exoskeleton has become an integral part of supportive technology for people with lower-limb paralysis, and in the past few years, numerous exoskeletons that restore the walking ability of people with complete paralysis have been developed. Some of them, like the ReWalk Personal 6.0 (ReWalk Robotics, Yokneam, Israel) and the Indego Personal (Parker Hannifin, Cleveland, OH, USA) were the first powered devices cleared by the Food and Drug Administration (FDA) for personal use. These devices proved their effectiveness in clinical settings.

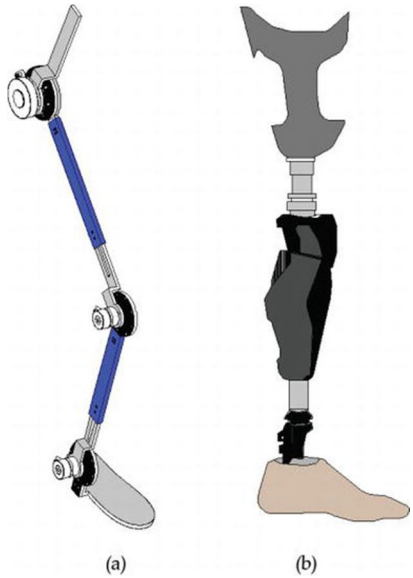
However, few robots have been applied in the clinical rehabilitation of patients with lower-limb paralysis, partly for the reason that the interfaces between the human body and most existing exoskeletons are unidirectional, and insufficient information interactions make the paralyzed patient incapable of controlling the exoskeleton robot well enough to coordinate it as they would, thus, leading to poor effectiveness in active rehabilitation of lower limb by the exoskeleton. Hence, a more effective interface should be developed to help the paralyzed rebuild the somatic motor system. The human body is a perfect control system with highly efficient information exchanges. The voluntary movements of a healthy human body, which occur as a result of conscious efforts originating in the brain, are controlled by the somatic nervous system (SNS). Nerve signals spread forward from upper motor neurons via axons to the lower corticospinal tract to control skeletal muscles in the form of action potentials. Furthermore, human proprioception is a third distinct sensory modality that provides internal feedback solely on the status of the body internally. The human motor system is a typical closed-loop control system with a proprioception feedback channel, which is the biological basis of human motion stability. However, most patients with lower-limb paralysis can neither control the motions nor perceive the motion status of their legs. Inspired by the closed-loop control system of the human body, a bidirectional human-machine interface is developed to help patients recover their ability to control and perceive their motions and to realize harmonious control of the human-machine system. The interface consists of a neuro-fuzzy controller that decodes the motion intentions in advance and transmits control information from the healthy side to the exoskeleton and an extended physiological proprioception (EPP) feedback system that transmits motion information of the paralyzed side from machine to human.

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IV. CLASSIFICATION OF AN EXOSKELETON

1) *Empowering Robotic Exoskeletons*: These sorts of robots are referred to as extenders since they extend the strength of the human hand beyond its aptitude while maintaining human control of the robot.
2) *Orthotic Robots*: An orthosis maps the anatomy of a limb to restore lost functions. The robotic counterpart of orthosis is robotic exoskeletons that complement the ability of the limbs. Exoskeletons also have the capacity to restore handicapped functions.
3) *Prosthetic Robots:* These kinds of robots are devices that fully replace lost limbs.

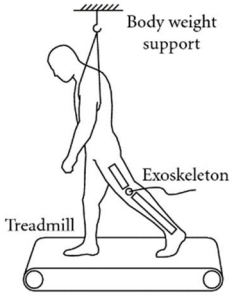


(a) Lower limb orthotic exoskeleton; (b) lower limb prosthetic robot.

V. TYPES OF EXOSKELETON

Over the last decade, several lower-limb rehabilitation robots are developed to revive mobility of the affected limbs. These systems are often grouped in keeping with the rehabilitation principle

A. Treadmill Gait Trainer



Traditional therapies usually specialize in treadmill training to enhance functional mobility [3]. This rehabilitation technique is understood as partial body-weight support treadmill training (PBWSTT). Three therapists assist the legs and hip of the patient by walking on a treadmill while part of the patient's body weight is supported by an overhead harness.

Of the ten systems that compose the group, only three of them are on the market: the Lokomat, the LokoHelp, and the ReoAmbulator. The Lokomat (Hocoma AG) consists of a robotic gait orthosis and an advanced bodyweight support system, combined with a treadmill. It uses computer-controlled motors (drives) which are integrated into the gait orthosis at each hip and knee joint. The drives are precisely synchronized with the speed of the treadmill to assure a precise match between the speed of the gait orthosis and the treadmill. To date, it is the most clinically evaluated system and one of the firsts of its type.

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B. Foot-Plate-Based Gait Trainer

Some rehabilitation machines are based on programmable footplates. That is, the feet of the patient are positioned on separate footplates, whose movements are controlled by the robotic system to simulate different gait patterns. The Gangtrainer GT I, commercialized by Reha-Stim, can assist the patient in the recovery of his freedom of movement by relieving the body of its weight and adapting speed from the individual ability of the patient [4].



Harness-secured patients are positioned on two-foot plates, whose movements simulate stance and swing, and ropes attached to the patient can control the vertical and lateral movements of the centre of mass. Many clinical studies have been conducted worldwide with this device [5], and it is considered one of the pioneering robotic systems for rehabilitation. Similar to treadmill gait trainers, the Gangtrainer GT I is effective because of the manual treadmill therapy but requires less input from the therapist.



The Haptic Walker is a haptic locomotion interface that can simulate slow and smooth trajectories (like walking on an even floor and up/down staircases) and foot motions like walking on rough ground or maybe stumbling or sliding, which require high-order system dynamics. HapticWalker is a major redesign of GT I with footplate trajectories fully programmable, and it's currently being clinically evaluated in several trials with stroke patients and spinal cord injury patients.

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C. Overground Gait Trainers

These systems consist of robots that servo-follow the patient's walking motions overground. They allow patients to maneuver under their control rather than moving them through predetermined movement patterns. It's very noticeable that almost all systems reviewed are commercialized.



KineAssist

The KineAssist is a robotic device, commercialized by Kinea Design, LLC, for gait and balance training [6]. It consists of a custom-designed torso and pelvis harness attached to a mobile robotic base. The robot is controlled in line with the forces detected from the subject by the load cells located within the pelvic harness. A recent test has been conducted so on judge overground walking speed changes when using the KineAssist system.

D. Stationary Gait Trainers

These robotic systems are focused on guided movements of limbs to have an optimal effect from a therapeutic and functional perspective. The objective of these systems is to obtain efficient strengthening of the muscles and the development of endurance and joint mobility and movement coordination.



The MotionMaker rehabilitation system

These robotic systems are focused on guided movements of limbs so as to own an optimal effect from a therapeutic and functional perspective. The objective of those systems is to get efficient strengthening of the muscles and also the development of endurance, moreover as joint mobility, and movement coordination. The MotionMaker (Swortec SA) is a stationary training system that allows to carry out fitness exercises with the active participation of the paralyzed limbs. The limbs are only hooked up to the orthoses at the foot level to simulate natural ground reaction forces. MotionMaker contains real-time sensor-controlled exercises, combined with the controlled electrostimulation, adapted to the patient's efforts and that's the advantage of it. First clinical trials are applied with the system, showing an improvement of the patient's ability to develop a better voluntary force during a leg-press movement.

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VI. ARTIFICIAL INTELLIGENCE TO HELP PARALYZED PATIENTS

A. AI-EEP System and Its Working

The problem with the exoskeletons is the additional burdens to patients with their heaviness and complexity to the caregivers. But there's an efficient and better way by which friends and caregivers can assist the paralyzed to enhance their lifestyle. Let's discuss the working of Artificial Intelligence-based Electroencephalograph (EEG) – Electromyogram (EMG) electrodes for Paralyzed (AI-EEP). This technique has been recently investigated by the middle for Robotics laboratory at SCMS School of Engineering and Technology, Cochin, India. This device will help paralyzed people move independently by using the recorded movements of a standard person as a reference [8].

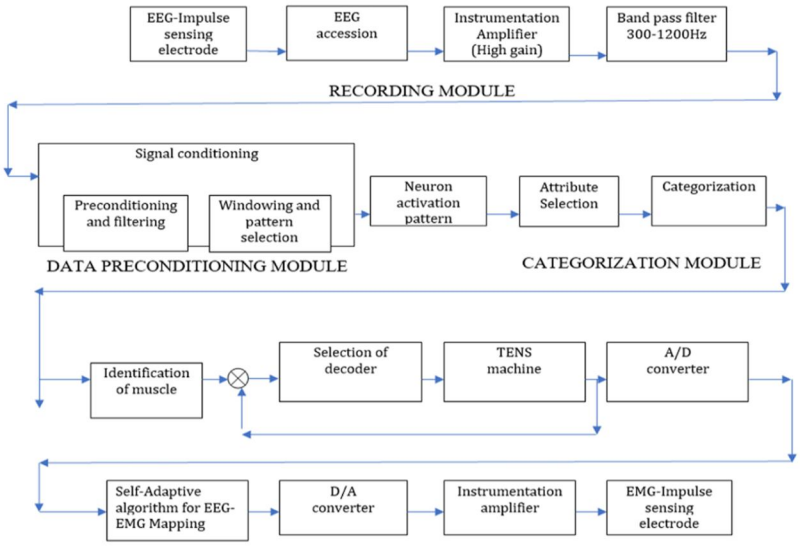
The working of the system is divided into two phases. In the first phase of the operation, the EEG signal of a standard person is recorded during voluntary movement using an EEG headset. This signal is fed as the input to the AI-EEP device and is used to set a threshold. The device then converts the EEG signals into corresponding two-dimensional movements, and the movements are classified based on the signal attributes. To measure the accuracy of this classification the number of correct classifications is divided by the number of physical movements.

In the second phase, the nerves accountable for the movement of specific muscles of the paralyzed person are identified. EMG electrodes are placed on these identified locations, and a Transcutaneous Electrical Nerve Stimulator (TENS) generates the desired nerve stimulation based on the recorded EEG signal. Performance accuracy is improved by a bio-feedback system [8].

B. System Architecture

1) *Recording Module:* The EEG signals taken from the EEG headset are first acquired by the AI-EEP device. A high gain instrumentation amplifier increases the strength of the impulses, and a bandpass filter is used to pick out the required range of frequencies before passing it to the conditioning module for preconditioning.
2) *Data Preconditioning Module:* This module consists of the signal features that are extracted after noise reduction, filtering and windowing, and desired attributes of the signal selected.
3) *Categorizing Module:* This module categorizes various EEG signals into predetermined muscle movement segments. The EEG signals first trigger the TENS device. The TENS device, in turn, generates the nerve stimulation and with the help of the EMG section, we get the desired muscle movement. The brain's neuron activity differs from person to person; the EEG signals of one person might not work for an additional. Also, the EEG signals of an individual for a specific thought will differ from time to time. Hence adaptability is a major issue in this project. The human muscle should adapt to the interface. For this, the decoded signal for muscle selection is obtained by a bio-feedback from the TENS device.

Below is ***The architecture of the proposed system depicting the flow of signals from the recording module to the pre-conditioning module and then to the categorizing module [8]***



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VII. DARPA-FUNDED INTELLIGENT SPINE INTERFACE

At the beginning of October 2019, Brown University announced a $6.3 million grant from DARPA to develop and test an intelligent read-write link for the spinal cord. Intel and Brown University have begun work on a DARPA-funded Intelligent Spine Interface project that aims to use AI technology to revive movement and bladder control for patients paralyzed by severe spinal cord injuries. The Defense Advanced Research Projects Agency (DARPA) is the center of the US Department of Defense liable for the event of emerging technologies to be used by the military. This project will be led by David Borton, assistant professor of engineering at Brown University School of Engineering and the Carney Institute for Brain Science.

Decades of research leading up to this point have shown that it is possible to reconnect some neural signals between the body and the brain.

"Recent studies have demonstrated that we are able to use electrical pulses to write down into the spinal cord for motor control, and that we are commencing to find out how to write down into the spinal cord for

sensory restoration, to some extent," says Borton. "We are now attempting to deal with the question that's always been there tantalizing us: can we 'bridge the gap' in a spinal cord injury?"

Borton began the work to read brain signals when he was a doctoral candidate at Brown in 2006. He was inspired by the work of colleagues who demonstrated the ability to show neural recordings into computer cursor control. That project was known as BrainGate. This groundbreaking system receives data from the leg area of the motor cortex and, almost like the computer-in-the-loop BrainGate system, relays that signal to a computer, which interprets whether the person wants to lift up the leg or put it down, then relays that information to a Medtronic neural structure stimulator that stimulates the nonfunctional limb.

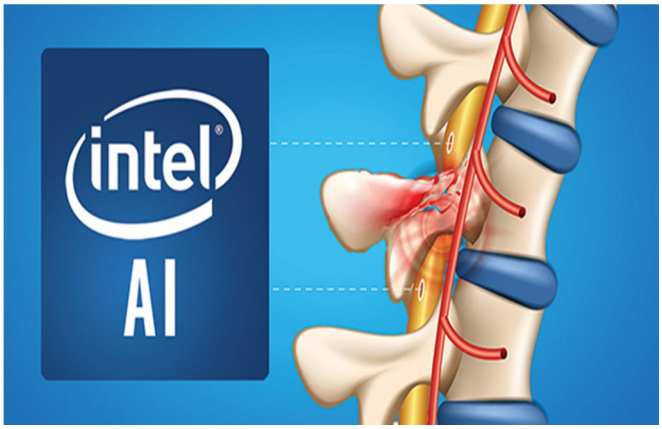


Diagram illustrating the spine-to-spine interface. Credit: Intel Corp.

The intelligent spinal interface will sit above and below the neural structure lesion and stimulate across that gap, utilizing an AI-trained computer chip to decode signals recorded from the spinal cord, retrain the remaining networks, and initiate the right intended behaviors. By leveraging the knowledge of the neural structure circuitry, they hope to coach the artificial neural network so it continues to learn over time.

VIII. CONCLUSION

While still at the development stage, this kind of ground-breaking research is an important step towards brain-controlled systems that could help to make life better for hundreds of thousands of people around the world.

The chips are created by Intel, one of the project's commercial partners, which features a division that focuses entirely on advanced neural compute architectures. The team is using Intel's open-source compilation library called nGraph, which allows neural network models to be compiled to different hardware targets. this suggests that an equivalent network code is often run on a server with tons of power or compiled right down to run on something with much less processing power, sort of a phone or, perhaps at some point, an implanted device.

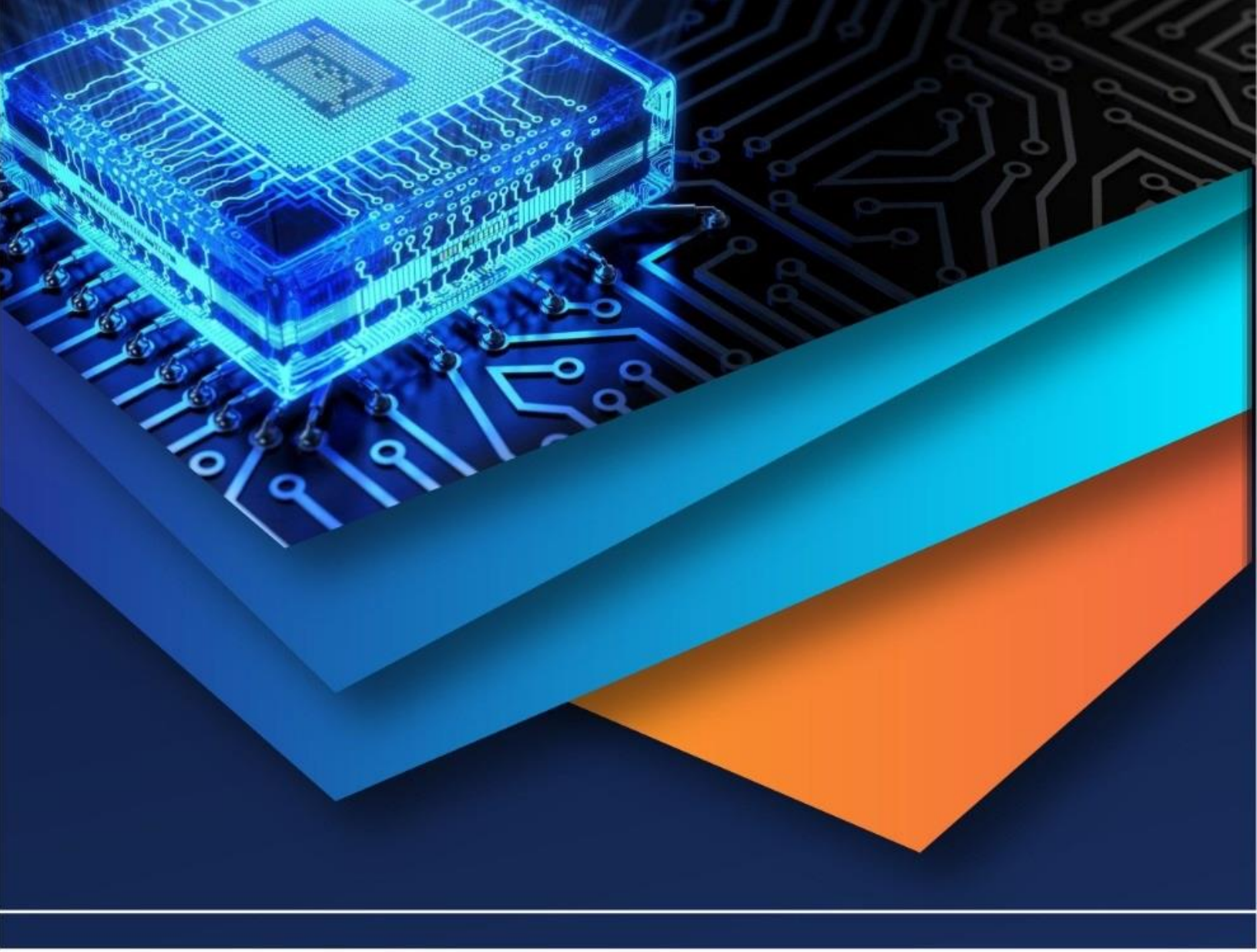
However, this brain–spine interface comes with risks, including a surgery to implant an electrode array, and a spinal surgery to implant the Medtronic spinal cord stimulator. Borton's team thinks it should be possible to create an electronic bridge from spine directly to spine, omitting the requirement for an invasive surgery.

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