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Social Robotic Systems in Autism Therapy: Survey and Design Considerations

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Abstract*: A few technology interventions have been developed to help autistic patients in their daily activities; among the most promising are social robots. Robots are likely to impact immensely in the therapeutic process of children with autism, because some prior research indicate that autistic children easily familiarize and interact with a robot companion than humans. In this paper, a survey of existing research on robots in autism therapy, discussion of design issues and identification of novel potential research ideas in social robotic systems for autism therapy are presented.
Keywords: Social robots; autism; therapy; design; evaluation

I. INTRODUCTION

Over the past few years, quite a number of robotic systems have been developed, ranging from simple and easy to program systems such as Lego® Mindstorms™, to highly sophisticated humanoid robots. These robots vary in their fields of use, levels of intelligence and task delegations. Typical application areas of robots include industry, household, health, education, social interaction and entertainment. Whereas some are used for highly complex surgical procedures, others serve as assisting systems for stress relief, social interactions and teaching motor skills. A group of robots usually referred to as social robotic systems, provide help to people through social interactions. Among the special group of people to benefit from social robotic systems are autistic children. Autism Spectrum Disorder (ASD), commonly referred to as autism, is a developmental disorder that encompasses a large variety of disorders with impairments in social relationships, communication and imagination[1]. This condition is termed a spectrum disorder because the level of severity varies among children. Autistic children usually have speech, social and motor skills impairments. Autism is a complex neurobiological disorder that cannot be cured. Currently, 1% of the world's population have been diagnosed with autism and the disorder can occur among all races and ethnic groups[2]. Very little is known about the causes of ASD. Autistic children find it very difficult to socially interact with others and often live in isolation thereby reducing their quality of life. How autism is managed in the initial stages affects the behavioural characteristics that would transcend into a child's adulthood. Prior research by [3],[1]have indicated that autistic children can easily familiarize and interact with a robot companion than a human. This is largely due to the fact that robots are more predictable and behave in the same way under the same set of conditions. The effectiveness of robotic systems for helping children with autism largely depends on their ability to continually engage, interact and adapt their behaviour in order to sustain the interest of such children. A few technological interventions such as virtual reality systems, dedicated software apps, robots and tele health systems have been developed to help autistic people in their daily activities. Most of these systems have not been widely adopted due to reasons such as their cost, inability to learn and adapt to the child as well as the need for intensive technical knowledge for controlling and manipulating the systems. Consequently, it is imperative that researchers model, design and test low cost but highly effective systems capable of helping to reduce autistic behaviour, as well to help in developing cognitive, speech and social skills. This paper seeks to contribute to research in social robotic solutions for autistic children by reviewing existing research, presenting design considerations and identifying future potential research and studies in social robotic systems for autism therapy.

II. ROBOTIC SYSTEMS FOR AUTISTIC CHILDREN

Research towards applicability of robots in autism therapy continues to record tremendous growth. Tables I and II present some of the existing studies on robots in autism therapy. Unlike typical "normal" developing children, autistic children are often self-absorbed in their own thoughts and tend to focus less on others or their environment. Observations from past research including [3],[4] indicate that autistic children show intrinsic interest in robots as compared to humans and toys. In a study by Werry et al.[5], children with ASD were made to interact with a robot and a non-animated toy; findings suggested that the children had more physical contacts, interactions and eye gazes with the robot as compared to the toy.

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Table I: A survey of some studies on anthropomorphic social robots in autism therapy

Robot	Description of robot	year	*NOP	Description of study
Robota	A humanoid robotic doll which is 50cm tall and weigh 500grams. The main boy of the robot consist of plastic components of a commercially available doll, wired with other electrical components	2004	4	longitudinal approach to analyse autistic childrens'interation with robots versus with humans [16].
		2002	14	robot engaged children in synchronous and imitative interaction game. Robot was tested on the children for a maximum of two consecutive days [37].
Kaspar	Size of a small child of about 3 years old. Kaspar can talk, sing rhymes, comb its hair and hold toothbrush. It is a minimally expressive robot	2014	6	Kaspar was used to facilitate the playing of games between pairs of children with autism. Study lasted for three weeks [14].
Nao	574mm autonomous robot programmed with games and applications to help autistic children. Looks more human-like but smaller than most children. Also quite expensive	2012	5	single session child-robot interaction where robot executed a series of human-robot interaction modules [11].
Maria	A mobile robot equipped with a monitor with the ability to display multimedia contents.	2016	ASD (N=5) Control Group (N=5)	Study was to determine the impact that incorporating multimedia content in a robot called Maria, would have on children with autism. A single session child-robot interaction was performed [17].
Zeno	Zeno is a humanoid robot which looks like a 4-7 year old child.	2011	1	Zeno was used to achieve natural head-eye coordination without the need of extensive kinematic analysis of the system. A person standing approximately 1.5 meters from the robot was tracked by the robot from face location images [38].

*NOP – Number of participants

The experiment conducted by Brian [6] with the ESRA robot, which was programmed to perform a roughly 2 minutes short "script" indicated that the autistic children involved were happy and tolerated the robot really well although it had no sensory, interaction and learning capabilities. In the beginning of the script, the robot "woke up" and asked an autistic child a few questions, and then fell back "asleep"; and the human instructor was also made to repeat the same questions the robot asked the child. The children

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however did not show much interest in the human instructor. A study conducted by Valentina [7] in Liguria, on a child with profound autism in a kindergarten school, focused on analysing the correct usage of a social robot, IROMEC, and verifying the possible outcomes of a robot to a human (teacher or child) communication. They reported an increase in child-robot eye contact and interaction as compared to that of the interaction between the child and teacher. In the course of the interaction, the child moved from a passive audience role and even enacted some of the actions of the robot.

Table II: A survey of some studies on nonanthropomorphic and nonbiomimetic social robots in autism therapy

Robot	Description of robot	year	*NOP	Description of study
Pleo (nonanthropomorphic)	Pleo is roughly like the size of a cat. It looks like a small dinosaur. It has the ability to react to new situations and different types of stimuli, to progressively develop new traits. It has a life-like ability to express different emotions and behaviours. Limited functionality. Slow locomotion	2013	24	Study compared the effects of interactions of 4 to 12 year-old autistic children with a social dinosaur robot, PLEO, against interactions with a human or a touchscreen computer game. Each child completed a sequence of three 6-minutes interactional conditions [15].
Keepon (nonanthropomorphic)	Keepon is a snowman-like 120mm tall robot. It has a simple design and uncomplicated mannerisms. It has four degrees of freedom	2006	25	25 infants with varying ages interacted with Keepon and their caregivers for a maximum of 15 minutes. Operators manipulated the robot to point to the direction of a child's gaze or towards an object with the "hope" of catching the child's attention [39].
Roball (nonbiomimetic)	Roball is a spherical ball-shaped robot that moves around by rotating its shell	2002	22	Roball was tested on a small number of children. During the experiment, the robot acted as a spinning and moving toy and tried to engage children in interaction [40].
Probo (nonbiomimetic)	Probo is an 80cm elephant-like robot. It has an actuated head which allows for the performance of a wide variety of facial expressions and sense its environment	2016	30	Probo was used in an interaction study with children with ASD to prepare fruit salad. [41].

*NOP – Number of participants

Reports from surveyed literature indicate that robots can be potential aids in teaching autistic children basic social skills such as emotions, imitation, speech and movement. Such robots can be classified under social robots since they "live" among and interact

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with humans[8]. Robots in autism can take on roles not limited to the following: therapeutic tool, playmate, social mediator, and model social agent [9].Among the early robotic projects in autism therapy was the Aurora project, which studied how mobile robots can serve as therapeutic tools for children with autism [10]. Children's use of nonverbal interactive resources, like gaze and declarative pointing to consciously focus on the same object with another person is termed as joint attention skills [11]. Autistic children have joint-attention deficits and therefore early proponents of robot assisted therapies for autism were geared towards improving joint-attention in these children. In the robot Keepon project, operators manipulated the robot to point to the direction of a child's gaze or towards an object with the "hope" of catching the child's attention[19]. Other studies that aimed at improving joint attention of autistic children using robots are [12] and [13]. Wainer et al.[14] evaluated how a humanoid robot, KASPAR, can be used to facilitate the playing of games between pairs of children with autism. KASPAR is an autonomous robot which can use information on the state of a game and behaviour of the children to motivate and advise the children on which moves to take during the game playing session. Detailed observations from their research showed that the autistic children exhibited improved social behaviours after robots participated in a triadic game session among the pairs of autistic children and the robot. Also, Kim et al.[15] compared the effects of interactions of autistic children with a social dinosaur robot, PLEO, against interactions with a human or a touchscreen computer game. Twenty- four (24) participants were randomly given the robot, or a human or a touchscreen computer game to interact with for six minutes. They observed that participants who interacted with the robot spoke more while interacting with the robot as compared with the children paired with humans and the computer. In 2004, Robins et al.[16] also investigated how a doll-like robot, ROBOTA, could be used to enhance shared attention, social skills and imitation among autistic children, their caregivers and other things in their environment.

The research conducted by Valadão et al.[17] sought to determine the impact of incorporating multimedia content in robots for children with autism. The researchers in the project developed the robot called MARIA and conducted a study with five ASD children and five without ASD (control group). The results obtained from their study indicated that social skills were stimulated in both groups and the robot also helped the children with ASD to pay more attention and interact with the robot. More so, findings from a pilot study by Shamsuddin et al.[18] in a single session child-robot interaction indicated that four out of the five autistic children used in the study exhibited a decrease of autistic behaviour (in communication subscale) when interacting with the robot Nao.

III.DESIGN CONSIDERATIONS AND ISSUES IN BUILDING ROBOTS FOR AUTISM THERAPY

A study conducted by Bartneck and Jodi[4] proposed a design centered approach needs to be adopted in the development of semi(autonomous) robots capable of interacting with humans and their environment. It further outlined some essential components which any social robot must possess: matching user's expectation, verbal and nonverbal communication and incorporation of societal norms into the design of the robot. Variables such as usefulness, adaptability, enjoyment, sociability, companionship and perceived behavioural control are also important factors which account for user acceptance of social robots [19]. Other features of social robots are outlined as follows:

1) *Shape, Size and Visual Appeal:* The visual appeal of a robot has an extensive effect on the ability of the child to sustain interest in continuous interaction with the robot. Most of the existing robots have physical shapes which can be placed under three categories: anthropomorphic, nonanthropomorphic or nonbiomimetic. Anthropomorphic robots have humanlike shapes and tend to exhibit some human characteristics. These robots typically have humanlike parts, physical shape, and are able to make facial expressions and other social cues. Developers of anthropomorphic robots do not necessarily aim at building artificial humans; rather, due to the robots close resemblance to humans, social interactions can easily be facilitated because humans like to interact the same way with machines as with other humans [20]. Nonanthropomorphic robots are designed to look more like animals and do not resemble humans; these robots are widely used as field and service robots. Nonbiomimetic robots are those whose shapes do not resemble humans, animals or any biological creatures; the behaviour and functionalities of such robots are not firmly rooted in biological principles. The size of social robots is also significant factor that can contribute to successful interactions between a robot and a person. Developers of robotic systems need to consider factors such as the environment in which the robot would operate and the tasks that the robot would perform. Irrespective of how technically impressive a robot is, its general appearance affects how people would perceive the robot [21]. Showmanship is also critical in how others perceive a robot. A robot with good visual appeal has a higher tendency to attract people. Some guidelines to create more visually appealing robots include: making robots look not very human, giving robots big eyes, using a maximum of two to three colours and avoiding the use of technical voices. In the physical design of robots for autistic children, some of the critical factors which need to be considered are:

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2) How would the robot's physical shape and size be? (i.e either anthropomorphic, nonanthropomorphic or nonbiomimetic)
3) Visual appearance (should the robot be covered with an artificial skin? or components of the robot should be exposed)
4) Mobility of the robot (would the robot be stationary or mobile?)

B. Sensory Rewards

Spaulding and Breazeal [22] argue that emotions plays a key role in human decision making and therefore, when robots are equipped with emotion sensing and expression capabilities, they are likely to exhibit higher performance in human-robot interaction applications. Praise as a form of social reward in human-human interactions can be a powerful tool which can be used to influence people's behaviour. When people are rewarded for their good work done, they feel positive and are even motivated to do better next time. A study by Okumura et al[23] investigated the effects that social rewards which are given by robots during human-robot interactions have on people; experimental results indicated that the test participants who received praise from robots exhibited a significant offline improvement in their motor skills as compared to those who did not receive any rewards.

C. Human-Robot Interaction and Evaluation Design

The ability of a robot to continually sustain the interest of autistic children can be influenced by many factors. Duquette et al.[24] outlines some of these factors as: mobility, appearance, behaviour and interaction modalities such as sound, light and moving parts. Factors which have significant influence on the effectiveness of robots in autism therapy also include the design and functionality of the robot [1]. The field of research aimed at investigating the applicability of robots as therapy partners in autism management has seen many studies producing varying results. According to [3], most of the research and studies on robots for autism therapy are classified under three categories: physical robot design, human-robot interaction design and the evaluations of robots in therapy-like sessions.

Developers of robotic systems need to decide on which human-robot interaction modes to use. The human-robot interaction design would determine how a robot would behave when it comes into contact with a human. Robots in autism therapy are aimed at continuously involving children in therapy sessions, and therefore the choice of human-robot interaction design plays a crucial role in the success of the robot. If a robot is successful in "catching" and maintaining the attention of a child, he may tend to like the robot and consequently learn from it. According to Scassellati et al.[3], some questions which need to be addressed by developers during the human-robot interaction design phase are as follows:

1) In which ways can the robot elicit behaviours such as joint attention, turn-taking, and imitation?
2) Would the robot be a standalone system which would operate alone or it would serve as an assistive technology for the therapist?
3) Would the robot be autonomous or tele-operated using the wizard of oz approach?
4) Would the robot be able to learn from its environment and adapt its behaviour to suit individual scenarios?

The final classification of robot studies as specified by Scassellati et al. [3] deals with the evaluations of robots in therapy-like sessions. After the robots have been successfully developed, they need to be introduced into therapy sessions in order to evaluate their effectiveness. These evaluations can be performed on a single-user or multiple users, interactions can be one-time or multiple times and evaluation metrics can be quantitative or qualitative or both. However, larger sample sizes are likely to increase the validity of the research and help to make generalized claims about the effectiveness of the robot.

IV. EVALUATING THE EFFECTIVENESS OF ASSISTIVE ROBOTS IN AUTISM THERAPY SESSIONS

Real-time sensing, analysis and modification of robot behaviour to suit its current environment is a major challenge in social robotics [25]. More often, robots are tele-operated in user studies in order to respond to changes in environment. Robots in autism therapy need to be evaluated in order to determine their effectiveness. Research by Goulart et al. [26], propose Goal Attainment Scaling (GAS), System Usability Scale (SUS) and Fitts' Law and also argue that the use of such methods of evaluation allows the transposition of qualitative assessments into quantitative, making research more robust and reliable. GAS is a technique for evaluating and quantifying the extent to which an individual has made progress towards set goals[27]. SUS, developed by John Brooke in 1986 can be used to evaluate the usability of a system and it consists of a 10 item questionnaire with five response options for respondents[28]. According to Fitts' Law, time to move to a target area is the function of the distance to the target and the target size [29]. Also, Feng at al.[30] proposed a model based on dynamic Bayesian Networks and experts elicitation for evaluating engagement in human-robot interactions. Feil-Seifer and Mataric[25] argue that if interpersonal distance between people can contain

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significant social and communicative information, then human-robot distances also convey social information. They also presented a system to distinguish positive reactions from negative reactions using Gaussian Mixture models.

Krupa et al.[31] also proposed a wearable wristband for acquiring physiological signals and an algorithm using a support vector machine (SVM) classifier, to predict emotional states such as neutral, happy and involvement of children with autism. Liu et al.[32] have developed a physiology-based affect-inference mechanism for robot-assisted intervention where the robot can detect the affective states of a child with ASD. In other evaluations by [24], [33] and [34], videos were recorded during the child-robot interactions, and the recordings were analysed at a later date for qualitative data. In most of the studies of robots in autism therapy, the amount of qualitative data outweighs the quantitative data; therefore researchers need to focus more on methods for collecting quantitative data in order to obtain substantial support for validity of research.

V. ETHICAL CONCERNS

In human-robot interactions, ethical concerns are a paramount issue and therefore, Syamimi et al.[35] recommend that ten layers of research protocol should be considered before commencing robot intervention programs in order to make adequate preparations and obtain consent from all the stakeholders involved. An ethical issue in robots for autism therapy lies in the degree of autonomy given to some robots. The more autonomous a robot is, the less control humans have over its behaviour. The question therefore is, who bears responsibility for a robot's action? Can parents trust the robots used in the therapy? Other ethical issues of concern are data privacy and security: would the data obtained from human-robot interaction be stored, how would the data be used and who would use the data? According to Coeckelbergh et al.[36], stakeholders approve of using robots in therapy for children with ASD, but prefer that the activities of these robots are controlled to some extent by therapists. More so, parents, caretakers, therapists and all stakeholders need to be properly informed about the details on how information collected during therapy sessions would be handled. Researchers should also seek parental consent for the participation of their children at all stages of the research.

VI. DISCUSSIONS AND CONCLUSION

Whereas the benefits of robots can be enormous, the world is yet to fully realize their potentials. An issue of concern is the fact that people feel that robots may take over the jobs of humans and therefore, people are reluctant to accept this technology. Perhaps, a more worrying factor is the tendency of autistic children to become emotionally attached to these robots. A few robotic solutions for autistic children exist; more so, most of them are in the prototype stages and are not available to be public. The very few which are available are very expensive and therefore are not being widely used. There is also limited research on the categories of shapes, sizes, and features of robots that would appeal most to children with autism. For example, would an autistic child prefer a humanoid to a nonhumanoid robot, or vice versa? Would a child prefer to play with a robot smaller than or bigger than him? Would a child be more stimulated by a moving robot or a stationary robot? Also, most of the robots developed for use in autism therapy are smaller than the children hence makes interaction a bit difficult. Self-presentation modes are virtually nonexistent in most robots used in autism therapy[17]. Before the robot-child interaction, robot self-presentation (i.e robot introducing itself) would help the child familiarize with the robot and also create a form of emotional bond. Robot self-presentation is likely to help a child who hitherto was scared to see the robot, become less tensed and more relaxed to interact with the robot.

Another feature which is seemingly missing from most of the robots for autism is the ability to incorporate interactive games which can be adapted to a child's needs. Controlling and manipulating majority of the existing robots usually require intensive technical know-how. More research needs to be carried out in order to develop learning algorithms to enable the robot to adapt to a child's cognitive abilities and behaviour. Most of the research undertaken in the area of robots for autism therapy has produced more of qualitative data than quantitative. Also, most of robot experiments undertaken involved a small number of participants over a short period of time. This is largely due to the fact that developing robots for autistic children need expertise from fields such computational science, mechanical and electrical engineering, robot control, human-robot interaction, social psychology, and clinical research[3]. Research groups may not be equipped with all these expertise and therefore tend to focus on activities in line with their capabilities. More so, children with autism are classified under "protected groups" and as a result, obtaining consent to engage them in long term studies becomes difficult. To alleviate this problem, roboticists need to collaborate with psychologists and clinicians in child-robot interaction studies. There is also the need for large scale long term longitudinal studies in order to obtain rich quantitative data for analysis. Another research area that needs to be addressed deals with how children from multicultural environments especially developing countries would behave and react when presented with the same robot under similar conditions.

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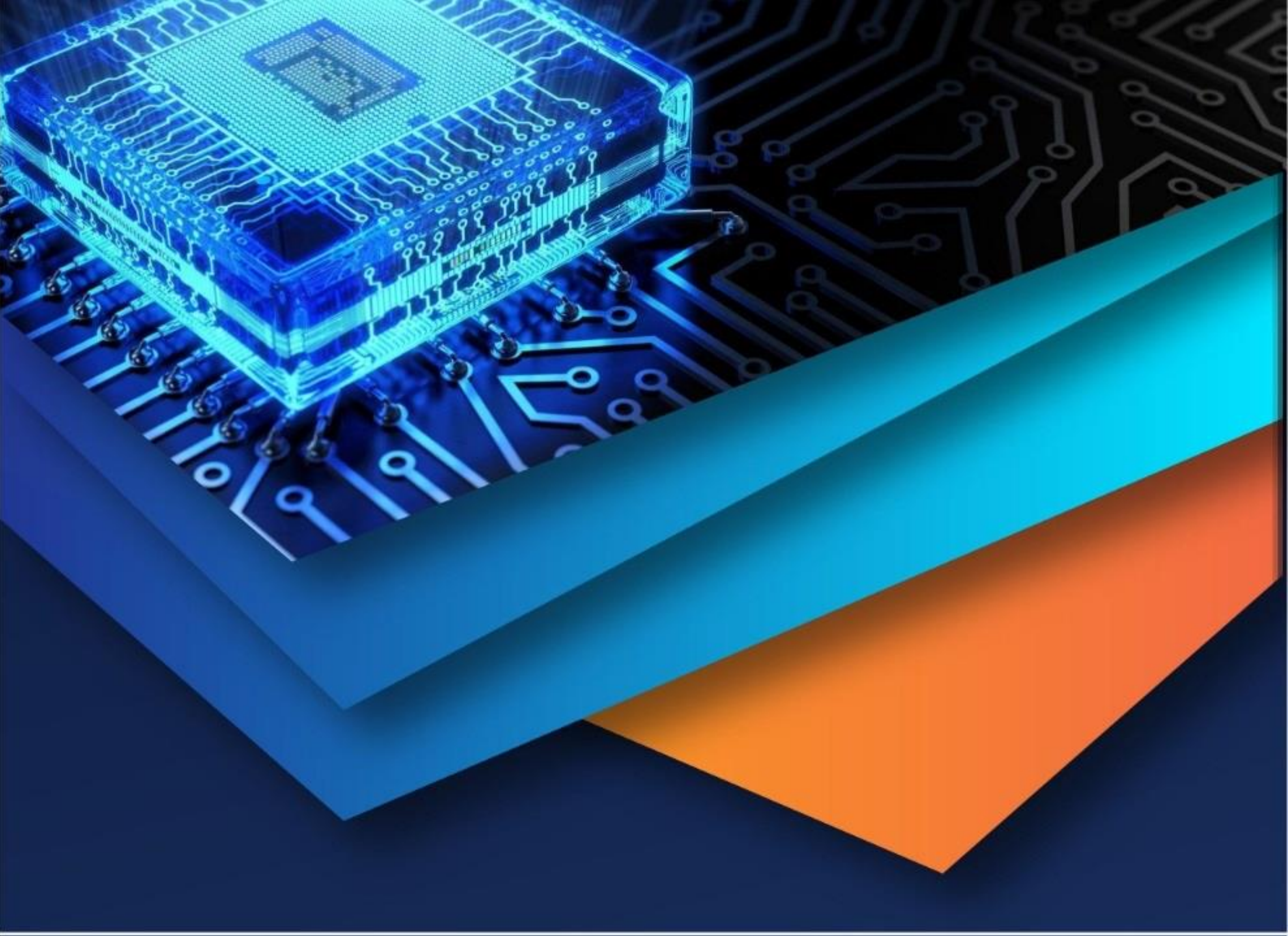

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