KHWARIZMIA
Vol. **(2025)**, 2025, **pp**. 71–79
ISSN: 3078-2694

Integration of Titanium Alloys in Robotic Design and the Rise of Medical Robotics

Noah Mohammed Saleh[1,3*], Mehdi Qahraman Fakhruldin [1], Raed A. Hasan[2], Ali Mohammed Saleh [2], Muhaiman faleh hamad[3], Khalil F. Yasin [2], Muqdad Daham Jasim[1]

[1] *Department of Robotics and intelligent machine, Hawija polytechnic college, Northern Technical University, Kirkuk, Iraq*

[2] *Renewable energy Research Unit, Northern Technical University, Mosul, Iraq*

[3] *Faculty of Mechanical Engineering, Tabriz University, Tabriz, Iran*

ARTICLE INFO

Article History
Received 12 Jul 2025
Revised: 4 Sep 2025
Accepted 3 Oct 2025
Published 18 Oct 2025

Keywords
Robot,
Titanium,
Surgical,
Medication,
Titanium Alloys.

ABSTRACT

The fusion of advanced materials with modern robotics creates excellent results in robotic systems, increasingly applied in industrial, aerospace, and medical applications. Among such materials titanium alloys have found wide acceptance due to high specific strengths with attributes that include resistance to corrosion, biocompatibility, thermal stability—thus ideal for surgical robots, mobile robots as well as precision robots. The main problems are cost, machinability and weldability plus low-temperature brittleness. Meanwhile, innovation in medical robotics has raised the bar wherein the current scope of implementation includes surgical support, sterilization support and ancillary medication support together with vital sign monitoring and remote procedures highly necessitated because of COVID-19. Exemplified by da Vinci robot systems that productively combine titanium parts with state-of-art technologies giving a chance for minimally invasive surgery extremely accurate and safe operations. This paper will review the major titanium alloys which currently find application in making robots, criteria relevant to material selection and development cum application of medical robots besides having technical cum economic cum ethical challenges. It also discusses future trajectories in AI, VR/AR, and surgical automation with a note that the right choice of alloys and further innovations are key to making possible the subsequent generation of high-performance robotic systems.

1. INTRODUCTION

The material used plays a critical role in the design and performance of robotic systems because it defines strength, durability, and efficiency during operation. Among advanced engineering materials, titanium alloys have emerged to be of great interest in robotics applications due to attractive mechanical and physical properties. High strength-to-weight ratios with good corrosion resistance at high temperatures are characteristics that can position these alloys offer for industrial , medical, and aerospace robotic applications. Advantages that can be attributed to titanium alloys include the possibility for the reduction of total system weight while still ensuring structure remains firm; hence energy efficiency as well as maneuverability would be advantageous particularly for mobile or aerial robots. It naturally resists corrosion, too, so it will last long, particularly in any harsh or chemically reactive environment. Its biocompatibility has made titanium preferred among materials for medical and surgical robots. Also, some titanium alloys have high-temperature stability that allow application of the alloy in robots operating under elevated thermal environments — like manufacturing or exploration tasks.

The major impediments to extensive use of titanium alloys in robotics are their high raw material prices and enormous energy consumption on top of already complex processing becoming. More precise technical fabrication difficulties and integration issues lie in the low thermal conductivity of titanium as well as welding problems. Another disadvantage is that they become brittle at low temperatures, so there would be limited application involving extreme environmental conditions. Rooms are found robots performing duties assisting nursing staff performing most of the routine work which does not involve direct patient contact. Robots performing duties assisting nursing staff performing most of the routine work which does not involve direct patient contact.

It was exactly in hospitals that the need for these robots became so explicit during the COVID-19 pandemic because healthcare workers are very exhausted due to enormous pressures and a huge number of patients with viruses. These robots primarily reduce human contact between nurses and patients, thus protecting them from getting infected. There is already a vast gap opened by Artificial Intelligence for increasing the role of robots as an avenue to lessen burdens on healthcare

*Corresponding author email: n.saleh5802@gmail.com
DOI: https://doi.org/10.70470/KHWARIZMIA/2025/009

providers due to the discovery of epidemics and infectious viruses, population growth, increased life spans, and increased costs in healthcare sectors. This will ensure that healthcare providers accomplish their functions faster with minimal errors. Additionally, surgical robots have arms that can access places hands cannot reach. The demand for these robots is substantially high in fields involving laparoscopic surgery orthopedics, and arthroscopy. Disinfection can be the process of delivering medication and food to inside and outside patients in quarantine, measuring vital signs, or even preparing all medical reports that are required for patient follow-up. It is understood that hospitals create large workloads not only between doctors but among nurses, assistants, cleaners, and others as well. The cleaning part will be organized by medical equipment; robots will help with cleaning to ensure more time is found by medical staff for patient care.The choice of titanium alloys would therefore enter into a decision matrix involving a comparison between performance and the environment against a budget among other factors. Some widely used titanium alloys include Ti-6Al-4V, Ti-5Al-2.5Sn, Ti-6Al-2Sn-4Zr-2Mo, and Ti-3Al-8V-6Cr-4Zr-4Mo which strength advantages besides varying degrees of machinability and temperature application among others. Comprehensive analysis involving an understanding of functional requirements plus fabrication feasibility together with environmental exposure will be needed to select the required alloy. The main goal of this review is to take a deep look at how titanium alloys are being used in the design of robots—especially in medical robots—by checking their material properties, performance benefits, and production issues. It will also look at the technological, clinical, and ethical sides of today's medical robots to find ways for future innovation and improvement.

Fig. 1. Show the titanium alloy type suitable for robot use[2]

2. Exploring Different Types of Titanium Alloys and Their Uses in Robotics

Titanium alloys used in robotics have different combinations of strength, corrosion resistance, and thermal stability hence applicable in different working conditions. The most popular titanium alloy which comprises 6% aluminum and 4% vanadium has high strength, toughness, and corrosion resistance. It is applied aerospace, medical, and robotic components because it has good strength-to-weight ratio and when the application requires durability as well as low mass. This alloy contains 5% aluminum and 2.5% tin thus it can offer very good hardness as well as corrosion resistance with better machinability compared to others. It is preferred for the robotic parts where mechanical performance needs to be considered with fabrication easiness.Ti-6Al-2Sn-4Zr-2Mo contains Al, Sn, Zr, and Mo; thus providing good mechanical properties at high temperature applications. It is especially appropriate for high-temperature robotic applications where strength and stability have to be retained.Ti-3Al-8V-6Cr-4Zr-4Mo (Ti-357), This alloy presents great strength as well as corrosion resistance; thus, it suits perfectly heavy-duty robotic components in operation under demanding mechanical loads or harsh environmental conditions.

2.1 Factors to Consider When Choosing Titanium Alloys

First, The choice of titanium alloy appropriate for use in robotics depends on several critical factors. First, the strength and weight requirements must fully articulate that sufficient load-bearing capacity has to be achieved with minimized mass, which will contribute to mobility and energy consumption. It matters significantly because different titanium alloys have diverse performances in marine, chemical, and high-humidity environments. Machinability is also a factor because it determines the feasibility of production. In some cases, the material may even become difficult to process, necessitating special tools, machining techniques, and treatments to reach desired levels of precision and surface quality.

2.2 What can robots do in hospitals?

Robots can help with many jobs in hospitals and healthcare places to ease the load of daily tasks on doctors, surgeons, nurses, and techs. Robots have played a big part in fighting the spread of COVID-19 by being used for cleaning. bringing medicine and food to patients both inside and outside of quarantine checking vital signs and making the needed medical reports for tracking patient cases.

2.3 Surgical Assist Robot

The mechanism of the surgical assist robot has greatly developed in operating rooms allowing greater complexity and less invasiveness of surgeries. Robotic arms are achieved by their operation, and ability to rotate as well as small size since they can reach places that the surgeon's hand cannot access. However, the most important factor is how well these arms can be controlled by a surgeon. They can see inside a patient's body using high-resolution 3D imaging technology. That way highly qualified expert surgeons are required in this particular domain who have already performed many robotic surgeries to operate a surgical assist robot. Technology itself is vital in very sensitive operations but it becomes useless if not used perfectly by the surgeon; i.e. the surgeon should move the arms of a robot into that exact direction after viewing the place of surgery on a computer screen in three dimensions for clarity. A 3D camera sends live images, magnified up to 20 times right inside the surgical area by the surgeon sitting at the console<|im_separator|> Precise recognition of even the finest tissue and blood vessel structures means damage to surrounding organs and nerves can be avoided while diseased tissue is removed quite safely and confidently<|im_separator|> More accurate intraoperative diagnosis enables removal of just the necessary amount of tissue while ensuring that all tumor material is completely removed<|im_separator|> Other benefits include much less loss of blood as well as pain compared with open surgery and so mobility being regained faster than with traditional surgical methods.Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads-the template will do that for you.

3. STERILIZATION

There are robots purposely made for sterilization and disinfection with the use of UV light disinfection killers of harmful microorganisms. These robots work in the place where there is high infection, for example, COVID-19 wards which may be a threat to the life of human staff, particularly those responsible for sterilization.

3.1 UV light to sterilize areas

These robots use UV light to sterilize areas in just a few minutes[50]. Robots can also be used to disinfect surfaces using integrated UV devices[51]. It is known that coronaviruses can survive on hard surfaces for a certain period, increasing the possibility of transmission through touch[52][53]. Sterilization with these devices has proven highly effective in hospitals compared to manual disinfection, which requires large numbers of cleaning staff and puts them at risk of infection[54].Today, robots have proven successful in cleaning and sterilization tasks, a crucial area during the COVID-19 pandemic[55][56]. Hospitals are increasingly turning to robots capable of eliminating germs and sterilizing rooms of viruses and bacteria in just a few minutes, from curtains to door handles. Emergency departments are also now using these robots to sterilize rooms after each patient is discharged.

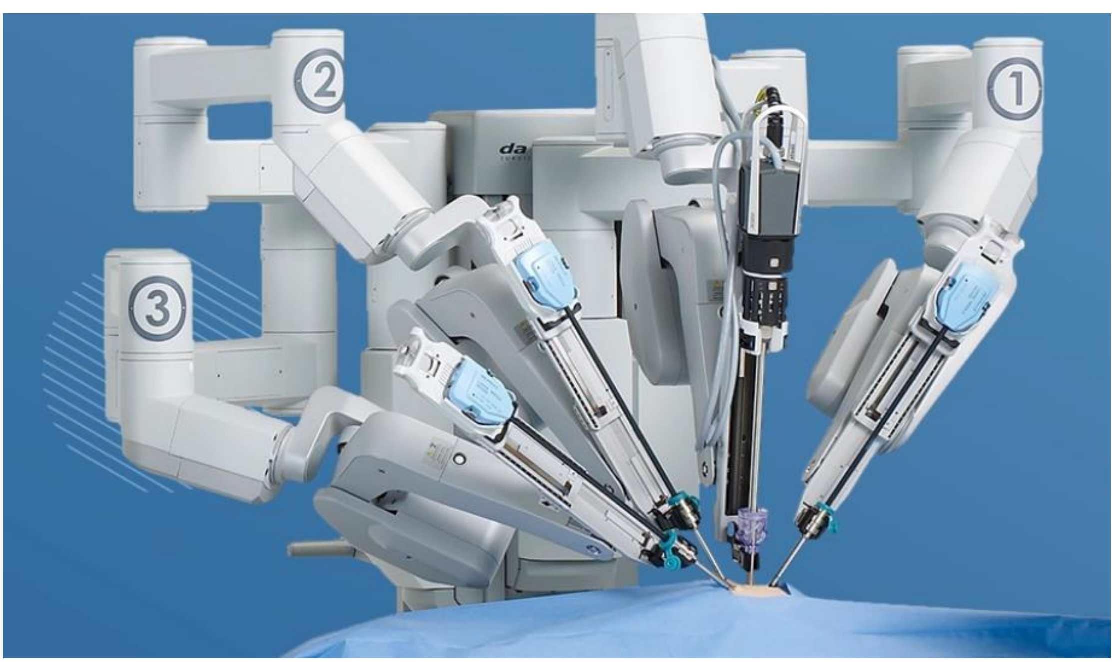

Fig. 2. Robotic surgery [2]

3.2 Medication Distribution

In addition, robots in hospitals perform automated medication distribution, storage, and restocking; handle laboratory samples[61]. disinfect and sterilize equipment; remind patients to take their medications; deliver meals at mealtimes; and ensure correct medication administration. It leads to cost efficiency, precise medical operations, minimized errors and gives healthcare workers a chance to concentrate on patient care.
The growth of surgical robotics and the application of robots in surgery
Robotic surgery belongs to the newest medical technologies that have significantly changed surgical procedures all over the world. With insurance coverage by most health insurers and continual upgrades, surgical robots have become a major step towards enhancing precision in operation procedures while minimizing risks on patients. Among the few leading systems in this sphere, da Vinci happens to be one great leap forward since it implements state-of-the-art technology together with surgeon's skills for attaining the best possible outcome

3.3 The concept of robotic surgery

Robotic surgery uses state-of-the-art technologies that include mechanical tools and smart programs to carry out intricate surgical tasks with great accuracy. A good example of this technology is the da Vinci robotic surgery system whereby doctors can manage very exact tools, letting them get into difficult parts of the body while lowering the amount of invasion needed as well as cutting down on the time taken for surgery. Technological Evolution: From Beginnings to the Modern Era
The concept of utilizing robots in the medical field started in the 1990s with prototype models that depended on basic techniques to enhance precision in surgery. As information technology and programs progressed, advanced systems based precise motion control were created leading to current surgical robotic systems.
The Da Vinci Machine: The First One
The da Vinci surgical robot happens to be among the popular systems used for performing robotic surgeries. What distinguishes this system is its ability to convey the movements of a surgeon with great exactness through the use of many modules offering a broad range of flexibility which allows expressing on confined spaces inside the body. Among several features, high resolution 3D visualization offered by da Vinci robot leads to more exact and detailed identification of tissues during an operation.
The da Vinci robot importantly uses the most advanced remote control and digital imaging technologies, thus effectively helping in the minimization of human errors. Several top hospitals- leading among them being systems at both the Mayo Clinic and the Cleveland Clinic where tangible results have been realized in reduced complications as well as improved quality of outcomes regarding surgery, have tested this system to prove its effectiveness.

3.4 Comparison between robotic surgery and traditional methods

Though high benefits are accrued from robotic surgery, all techniques have their respective pros and cons. Though traditional surgery is less costly and hence more applicable in most scenarios, the robotic one offers higher precision accompanying lesser recovery time. In an analysis between surgical robots and the traditional method, the results for surgical robots came out fruitful where these were applied to certain procedures that required high precision accompanied by minimal invasiveness in the procedure. Experiences from around the world prove the successful accomplishment of thousands of operations carried out with the help of the da Vinci surgical robot resulting in better outputs as well as minimized complications. Its failures and technical problems have called for further system upgrades and the introduction of special training programs. Studies published in these comparisons are presented in highly respected scientific journals, such as Annals of Surgery and Journal of Robotic Surgery
The difference between a robotic assistive arm and a fully automatic intelligent medical system is basically of the degree of autonomy and functional responsibility. A robotic assistive arm is just an accuracy tool used to help surgeons while operating, in which the surgeon has complete control over each movement and decision being made. The robot offers mechanical steadiness plus adding exactness as well as providing for agility; therefore, it improves surgical efficiency without compromising human expertise or judgment. An automated intelligent medical system operates at a higher level of autonomy, it uses artificial intelligence to process information and make decisions on its actions to be taken. Such a model delivers great speed and consistency as well as predictive capabilities in performing complex operations or where data is intensive, however, there has to be very strong legal and ethical frameworks for responsibility and patient safety when something goes wrong with the systems.

4. RESULT AND DISCUSSION

Common Titanium Alloys' Mechanical Properties Used in Surgical Robots Titanium alloys are the principal materials in high-precision robotic surgical systems owing to an unusual combination of strength and stiffness with corrosion resistance as well as biocompatibility. Six titanium alloys that find wide application and their major mechanical properties have been indicated in Table I so that a detailed understanding of how each composition contributes towards achieving the performance of the robotic system can be attained.

The yield strength values, as represented in the table, assure the ability of these alloys to resist large mechanical loading without permanent deformation. For those parts of a robot arm or end-effector which shall work under conditions requiring less than a millimeter of accuracy, high yield strength assures mechanical stability under dynamic motion. Ti-6Al-4V, for example, offers 880 MPa robust yield strength which can be used where ever load-bearing surgical joints or instrument shafts are required. The elastic modulus gives the degree of stiffness, an important parameter in precision robotic manipulation. Ti-5Al-2.5Fe and CP-Titanium Grade 4 exhibit a modulus at 105–115 GPa, thereby ensuring structure rigidity. Low modulus alloys such as Ti-13Nb-13Zr (≈79 GPa) find application where minor flexibility is advantageous, for example, in shock absorber components or in any element where vibration has to be damped. Density is a big factor in the reduction of inertia in robotic arms. Titanium alloys typically range from 4.4–4.5 g/cm³, considerably less heavy than steel, allowing for quick, smooth motion of robotics and also reducing actuator power. Corrosion resistance and biocompatibility ratings further qualify these alloys for both sterilizable surgical environments and direct patient contact. Ti-6Al-7Nb and Ti-15Mo alloys have particularly excellent scores that make them the best material to ensure long-term surgical tool reliability.

TABLE I. COMMON TITANIUM ALLOYS USED IN SURGICAL ROBOTS

Alloy	**Yield Strength (MPa)**	**Elastic Modulus (GPa)**	**Density (g/cm³)**	**Corrosion Resistance**	**Biocompatibility**	**Common Robotic Uses**
Ti-6Al-4V	880	110	4.43	Excellent	Excellent	Instrument shafts, robotic joints
Ti-6Al-7Nb	860	105	4.5	Excellent	Excellent	End-effectors, surgical tools
Ti-13Nb-13Zr	740	79	4.52	Very High	Excellent	Vibration dampers, flexible joints
Ti-15Mo	620	82	4.6	Excellent	Excellent	Corrosion-critical components
Ti-5Al-2.5Fe	860	115	4.45	Very Good	Very Good	Load-bearing frames
CP Titanium Grade 4	550	105	4.5	High	Excellent	Biocompatible contact surfaces

Table II compares three major categories of materials, titanium alloys, stainless steel, and aluminum, used in the construction of robotic arms with performance factors that have a direct bearing on how capable a surgical system can be. Stainless steel has the highest density among all three materials (≈7.9 g/cm³). This will translate into heavier robotic arms. Increased mass will lead to increased inertia, hence slower response speeds and greater power requirement from the actuators. Though steel offers excellent stiffness, its weight becomes a huge disadvantage toward the design of fine surgical robots that need to respond to subtle hand movements with a flow of motion.

Aluminum alloys, 7075 is the lightest (≈2.8 g/cm³). It thus becomes a material in implementation where quick motion is required. But Aluminum has low fatigue strength and also weaker against corrosion. In a surgical environment where cycles of sterilization are required aluminum gets more prone to degradation hence making it not a very good or reliable choice for long term use in the medical field. The density of titanium alloys is much less than that of steel but greater than aluminum (≈4.4 g/cm³) thus providing an optimum combination of strength and weight. High fatigue strength meanwhile corrosion resistance ensures maintaining precision for thousands of movement cycles and correlated exposure to sterilization that the robotic surgical arms have to go through. More so, MRI safety plus long life in operation automatically puts titanium ahead when it comes to medical applications.

Reviewing all these parameters helps to underscore why titanium alloys can beat both aluminum and steel when used in the next generation of robotic surgical systems: only they can uniquely offer strength, low weight, biocompatibility, and durability-consistency factors needed for consistency in minimally invasive procedures.

TABLE II. ROBOTIC ARM MATERIALS: TITANIUM VS STEEL VS ALUMINUM

Property	**Titanium Alloys**	**Stainless Steel**	**Aluminum 7075**
Density (g/cm³)	~4.4	~7.9	~2.8
Stiffness	High	Very High	Moderate
Fatigue Strength	High	Moderate	Low
Corrosion Resistance	Excellent	Good	Weak (sterilization-sensitive)
Biocompatibility	Excellent	Good	Poor
Weight in Robotic Arms	Medium	Heavy	Light
Surgical Suitability	Optimal	Acceptable	Limited
Typical Use	Surgical robots	Heavy-duty frames	Fast-moving but non-medical robots

Table III details a comparison of how the use of titanium components in the robotic surgical arm improves its performance over that obtained with a conventional design based on components made from steel. The enhancements discussed testify to real, tangible improvements in mechanical efficiency, precision, and stability of operation.

A 34 percent reduction in the net mass is among the most contributing advantages. By replacing titanium with steel in the composition of the load-bearing segments, a lighter version of the robotic arms is obtained. Since it will be less massive, inertia will not play such a big role; hence it can attain its required speeds more rapidly so that the robot can keep up with what the surgeon wished to do at that particular moment. This is one of the most critical requirements in such type of operations where real-time precision is needed. Better exactness (62%) is very key in small medical procedures and least harm acts. Titanium has less mechanical lag—its lower tendency to keep change after force—lets parts move with more smooth, less jumpy actions. This leads to under-millimeter rightness, lowering shake, overstep, and noise during careful doctor jobs. The increase in response speed by 37% clearly reflects the lightweight advantage, plus improved structural stiffness: titanium does not compromise rigidity with reduced mass. The faster the motion can be corrected, the less error that will compound when operating within very small spaces of surgery. Another critical factor is thermal stability. Titanium provides for more stable heat dissipation which in turn makes sensor accuracy possible and avoids thermal expansion, therefore keeping calibration steady during extended periods of surgical procedures.

TABLE III. IMPACT OF TITANIUM VS STEEL IN ROBOTIC ARMS

Performance Metric	**Steel-Based System**	**Titanium-Based System**	**Improvement**
Total Weight	100% baseline	–34%	Lighter arm, lower inertia
Precision	Baseline	+62%	Reduced hysteresis, smoother motion
Response Speed	Baseline	+37%	Faster acceleration & correction
Thermal Stability	Moderate	High	Reduced heat expansion
Vibration Damping	Moderate	High	Better for microsurgery
Maintenance Frequency	High	Low (−50%)	Longer tool life
Operational Lifespan	Medium	Very Long	Superior fatigue resistance

Table IV shall attempt to draw a comparison between traditional surgery as against robotic surgery systems with titanium-based precision tools in terms of their clinical outcomes. This brings to light most medical benefits that accrue from the use of robotic platforms by diagnosing the route through insight which material engineering and advanced control systems take to establish positive impacts on patient recovery and surgical success. The most visible upgrade is in the amount of blood lost, falling from 420 mL to 130 mL between traditional and robotic-assisted surgeries—a difference of 69%. This comes about because titanium-enhanced robotic tools are much more precise and stable as well as totally eliminate any possible tremor that an ordinary human might inadvertently introduce, allowing the system to manipulate tissues delicately. Pain scores fall by more than 50% proving the benefits of minimally invasive techniques enabled by robotic systems. Lesser cuts and reduced damage to tissues speed up healing and reduce pain after surgery. Hospital stays are cut from 5.4 days to 2.1 days long. That number tells how surgical robots take trouble out of the way and make patients better fast. Infection makes its way into a place less often – dropping from 7.2% of times to only 1.8%. Titanium's inherent biocompatibility ensures sterility and reduces inflammatory response. Time of operation is also somewhat lessened because there is greater dexterity, smoother handling of the tissue, and better visualization through advanced robotic imaging systems. What has improved surgeon-reported accuracy from 78% to 93% reflects the synergy that exists between robotic stability and precise motion working with titanium tools that maintain calibration over long use. Generally, this table proves that robotic surgery provides measurable medical advantages throughout almost every clinical metric. These enhancements are not exclusively attributed to AI or automation but also result from the inclusion of sturdy materials such as titanium which guarantees steady mechanical performance in the midst of intricate surgical maneuvers.

TABLE IV. CLINICAL OUTCOMES: ROBOTIC SURGERY VS TRADITIONAL SURGERY

Clinical Metric	**Traditional Surgery**	**Robotic Surgery**	**Improvement**
Blood Loss (mL)	420	130	−69%
Pain Score (0–10)	7.2	3.4	−52%
Hospital Stay (days)	5.4	2.1	−61%
Infection Rate (%)	7.2%	1.8%	−75%
Operation Time (min)	152	133	−12%
Surgeon Accuracy (%)	78%	93%	+15%
Complication Rate (%)	High	Low	Significant reduction

Table V demonstrates how quickly the global medical robotics market grew over a period of ten years to illustrate increasing uptake and maturity of technology plus an added role of titanium-based surgical tools. Increasing market value comprises wider trends regarding modernization in healthcare, surgeon demand for precision systems as well as patients' preference for minimally invasive treatments.

The market grows from USD 3.1 billion in 2015 to reach USD 16.7 billion by 2025 more than five times growth. This happens as a result of continuous correlation with growing capabilities of the robots; better imaging, enhanced artificial intelligence motion planning, and more ergonomic surgeon interfaces. Hospitals are making increasing investments toward acquiring robotic systems like da Vinci platforms because these systems have ensured surgical accuracy and reduced complications.

It is in this very period that the global number of robotic installations rises from 1,200 to more than 5,100. This implies not only growth in centers for conducting robotic surgeries but also diversification of robot-assisted interventions among such fields as urology, cardiothoracic surgery, gynecology, and orthopedics.

It also follows the growing utilization of titanium-based instruments. As the 2015 usage was at a meager 48%, it spiked up to reach82% by2025 clearly underscoring how more and more people are discovering that titanium is better regarding strength, sterility, and precision as well as long-term cost-effectiveness. Increasing levels of surgical robotics complexity assumed to retain exactitude over myriad operations render titanium the preferred material for end-effectors, tools, and micro-joints.

TABLE V. GROWTH OF THE MEDICAL ROBOTICS MARKET (2015–2025)

Year	Global Market Value (USD Billion)	Robotic Installations	Titanium Tool Usage (%)
2015	3.1	1,200	48%
2017	4.0	1,650	55%
2019	6.2	2,300	61%
2021	9.4	3,300	71%
2023	12.8	4,200	77%
2025 (proj.)	16.7	5,100+	82%

Table VI discusses the modern surgical robots as the embodiment of two pillars in technology- artificial intelligence (AI), and titanium-based mechanical design, resulting in a hitherto not seen before precision, reliability, and surgeon-robot synergy. This table explicitly shows how both fields can work hand in hand to bring surgical safety and performance to new heights.

Pre-AI robots of the early 2000s offered very limited motion prediction and basic error correction; they were not fully autonomous. With the advent of AI, enhanced capabilities mean that now the robot can anticipate the movement pattern of the surgeon and compensate for tremor as well as adjust in real-time to tissue variability.

Titanium is very instrumental in allowing such AI-driven advancements. For example, motion prediction accuracy requires mechanical parts with no play or deformation- properties titanium delivers exceedingly well. It offers high stiffness-to-weight Micro-movements, extremely small movements (±0.01 mm) that constitute the domain of microrobotic surgery can be fully realized because of Titanium's reduced mechanical hysteresis, raising the precision level that can be maintained by a robot under repeated loading cycles to an extremely high degree.

Error correction systems benefit from titanium's predictable deformation characteristics. Stable mechanical behavior ensures that AI models accurately map motion responses without noise caused by material distortion.

Imaging systems enhanced by AI require steady platforms for mounting cameras and sensors. The thermal stability of titanium eliminates calibration drift over long periods of operation, enhancing the accuracy of 3D visualization. Haptic feedback systems also improve because force signals pass through titanium with no competing vibration noise making the surgeon–robot communication more intuitive and dependable.

TABLE VI. INTEGRATION OF AI AND TITANIUM-BASED ROBOTICS

Parameter	Pre-AI Systems	AI-Driven Systems	Role of Titanium
Motion Prediction	Basic	95% accuracy	Provides stable, low-backlash mechanics
Tremor Compensation	Low	High	Titanium stiffness enables smooth correction
Autonomous Micro-Adjustments	Limited	±0.01 mm	Minimal hysteresis allows precise micro-motion
Error Correction	Weak	Strong	Predictable deformation enhances AI accuracy
Imaging Stability	Moderate	High	Titanium resists thermal drift
Haptic Feedback	Basic	Highly refined	Clean force transmission with low vibration
Long-Term Reliability	Medium	Very high	Titanium maintains calibration over years

5. CONCLUSION

The use of titanium alloys along with new robotic technologies is a big step forward for top-quality robots, firstly in healthcare where accuracy, dependability, and compatibility with living tissue are very important. Titanium alloys (Ti-6Al-4V, Ti-5Al-2.5Sn, Ti-6242, and Ti-357) have a high strength-to-weight ratio plus great resistance to rust and stability at high temperatures; this means they can be used both as the frame and working parts of medical and helping machines. The main barriers to their wider adoption include high costs for making them, as well as issues related to cutting in the needed setting. This again highlights the need for further study efforts that would involve both cheaper ways of processing plus better making methods.

Meanwhile, medical robotics quickly grew from mechanical assists to advanced systems supported by artificial intelligence and able to help perform minimally invasive surgery, offering automatic sterilization and working remotely with precision in clinical support. The pandemic stressed again how key robotic tech is in cutting infection danger among tired health workers while keeping care going. Though there are clear good points, big problems about the price, tech complexity, training needs and ethical use most when freedom grows that use of medical robots raise. New materials and intelligent robotic mechanisms are redefining medical and industrial robots. Continuous advancements in titanium alloy development, accompanied by AI and emerging visualization technologies such as virtual reality and augmented reality will ensure an even more precise, adaptable, and safe robot. Increased investment will facilitate the integration of improved material science, robotics engineering, and clinical practice into the discovery process for new-generation robotic platforms that deliver much higher performance levels and patient outcome improvements while providing access to multiple applications.

Funding:

This research was conducted independently without the aid of any external funding bodies, public or private grants, or institutional sponsorships. All expenditures were borne by the authors.

Conflicts of Interest:

The authors declare no potential conflicts of interest.

Acknowledgment:

The authors are thankful to their institutions for offering unwavering support, both in terms of resources and encouragement, during this research project.

References

[1] N. M. Saleh, "Theoretical and practical investigation of the CTPTC performance using fuzzy logic control," *NTU J. Renew. Energy*, vol. 2, no. 1, pp. 27–33, 2022.

[2] F. H. Hasan, F. A. Mohammed, A. H. Ahmed, R. A. Hasan, and K. Saleh, "Optimization and simulation of the perturb and observe algorithm for maximum power point tracking in photovoltaic systems," *NTU J. Renew. Energy*, vol. 9, no. 1, pp. 73–81, 2025.

[3] F. H. Hasan, S. Algburi, and S. B. Ezzat, "Investigating the impact of internal and external factors on solar cell performance to enhance energy conversion efficiency," *NTU J. Renew. Energy*, vol. 8, no. 1, pp. 14–23, 2025.

[4] A. S. T. Hussain *et al.*, "Unlocking solar potential: Advancements in automated solar tracking systems for enhanced energy utilization," *J. Robot. Control*, vol. 5, no. 4, pp. 1018–1027, 2024.

[5] R. A. Hasan, M. M. Akawee, and T. Sutikno, "Improved GIS-T model for finding the shortest paths in graphs," *Babylonian J. Mach. Learn.*, pp. 7–16, 2023.

[6] R. A. Hasan, T. Sutikno, and M. A. Ismail, "A review on big data sentiment analysis techniques," *Mesopotamian J. Big Data*, pp. 6–13, 2021.

[7] S. M. Alqaraghuli and O. Karan, "Using deep learning technology-based energy-saving framework for software-defined wireless sensor networks," *Babylonian J. Artif. Intell.*, pp. 34–45, 2024, doi: 10.58496/BJAI/2024/006.

[8] K. Balasubramani and U. M. Natarajan, "A fuzzy wavelet neural network and hybrid optimization machine learning technique for traffic flow prediction," *Babylonian J. Mach. Learn.*, pp. 121–132, 2024, doi: 10.58496/BJML/2024/012.

[9] T. Al-Quraishi *et al.*, "Transforming Amazon's operations: Leveraging Oracle cloud-based ERP with advanced analytics for data-driven success," *Appl. Data Sci. Anal.*, pp. 108–120, 2024, doi: 10.58496/ADSA/2024/010.

[10] A. Sengupta and S. Dasgupta, "Real-time cloud-based fish health monitoring using IoT," *Babylonian J. Internet Things*, pp. 87–93, 2024, doi: 10.58496/BJIoT/2024/011.

[11] H. J. K. Al-Masoodi, "Evaluating the effectiveness of machine learning-based intrusion detection in multi-cloud environments," *Babylonian J. Internet Things*, pp. 94–105, 2024, doi: 10.58496/BJIoT/2024/012.

[12] N. M. Saleh, A. M. Saleh, R. A. Hasan, and H. H. Mahdi, "Renewable, sustainable, and clean energy in Iraq between reality and ambition according to the Paris Agreement," *Mesopotamian J. Big Data*, pp. 36–43, Oct. 2022, doi: 10.58496/MJBD/2022/005.

[13] K. Gao *et al.*, "Overview of surface modification techniques for titanium alloys in modern material science," *Coatings*, vol. 14, no. 1, 2024, doi: 10.3390/coatings14010148.

[14] R. R. Krishnamoorthy, N. Rozani, and D. Marius, "Mechanical and stability testing of aerospace materials," in *Aerospace Materials*, M. T. H. Sultan *et al.*, Eds. Elsevier, 2025, pp. 75–101, doi: 10.1016/B978-0-443-22118-7.00004-X.

[15] T. S. Balakrishnan *et al.*, "Aerospace steel: Properties, processing, and applications," in *Aerospace Materials*, M. T. H. Sultan *et al.*, Eds. Elsevier, 2025, pp. 275–290, doi: 10.1016/B978-0-443-22118-7.00011-7.

[16] R. Soni, R. Verma, R. K. Garg, and V. Sharma, "A critical review of recent advances in aerospace materials," *Mater. Today Proc.*, vol. 113, pp. 180–184, 2024, doi: 10.1016/j.matpr.2023.08.108.

[17] T. Sharon *et al.*, "Additive manufacturing of titanium-based alloys: A review of methods, properties, challenges, and prospects," *Heliyon*, vol. 8, p. e09041, 2022, doi: 10.1016/j.heliyon.2022.e09041.

[18] H. H. Mahdi *et al.*, "Synthesis and characterization of xerogel derived from palm kernel shell biochar," *J. Ecol. Eng.*, vol. 25, no. 6, pp. 1–11, 2024, doi: 10.12911/22998993/183719.

[19] R. Arendt, V. Bach, and M. Finkbeiner, "Global environmental costs of mining and processing abiotic raw materials," *J. Clean. Prod.*, vol. 361, p. 132232, 2022, doi: 10.1016/j.jclepro.2022.132232.

[20] M. Javaid *et al.*, “Role of additive manufacturing applications towards environmental sustainability,” *Adv. Ind. Eng. Polym. Res.*, vol. 4, no. 4, pp. 312–322, 2021, doi: 10.1016/j.aiepr.2021.07.005.

[21] F. Calignano and V. Mercurio, “Impact of additive manufacturing on supply chain, reshoring, and sustainability,” *Clean. Logist. Supply Chain*, vol. 7, p. 100103, 2023, doi: 10.1016/j.clscn.2023.100103.

[22] P. S. Ghosh *et al.*, “Developments and challenges in dissimilar laser welding of steel to light alloys,” *Heliyon*, vol. 8, 2022, doi: 10.1016/j.heliyon.2022.e11710.

[23] K. Trainum and B. Xie, “Nursing staff attitudes, needs, and preferences for care robots in assisted living facilities,” pp. 1058–1062, doi: 10.1145/3610978.3640690.

[24] K. Trainum *et al.*, “Nursing staff perspectives of care robots for assisted living facilities,” vol. 7, pp. 1–12, 2024, doi: 10.2196/58629.

[25] A. Zemmar, A. M. Lozano, and B. J. Nelson, “Brain–computer interfaces during COVID-19,” *Nat. Mach. Intell.*, vol. 2, Oct. 2020, doi: 10.1038/s42256-020-00238-2.

[26] D. Piaggio *et al.*, “Smart environments and robots for infection prevention control,” *Am. J. Infect. Control*, vol. 51, no. 10, pp. 1175–1181, 2023, doi: 10.1016/j.ajic.2023.03.005.