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# Robots for minimally invasive diagnosis and intervention

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ABSTRACT

Minimally invasive diagnosis and interventions provide many benefits such as higher efficiency, safer, minimum pain, quick recovery etc. over conventional way for many procedures. Large robots such as da-Vinci are being used in this purpose, whereas research of miniature robots for laparoscopic and endoscopic use, is growing in the recent years. A comprehensive literature search is performed using keywords' laparoscopic robot, capsule endoscope, surgical medical robot etc. primarily for the time period of 2000–2015. The articles relevant to the theme of the paper are reviewed and included in the paper. This paper concentrates medical robots for minimally invasive diagnosis and intervention in general and propulsions of miniature robots in particular. Robots are classified and compared using critical characteristics and summarized in Tables 1–6. Large robots such as da-Vinci are successfully used in many procedures e.g. neurosurgery, cardiothoracic surgery etc. However there are needs for more functionality which might lead to flexible robots. For miniature robots, each propulsion mechanism has some advantages and disadvantages. While external magnetic propulsions have potential to provide propulsion without increasing the robot size, they lack precise position control and may require expensive and bulky equipment. On the other hand internal propulsions have the capability of precise position control but require mechanisms which need substantial amount of power to drive. Hybrid propulsion which combines best features of both internal and external propulsions could be a solution for this. Robots have improved the healthcare services for many medical procedures. However, still there are challenges to address to enable use of medical robots universally inside and outside hospitals for diagnosis and interventions.



## 1. Introduction

Robots came into reality from fantasy world in 1961 when general motors introduced Unimate in the automobile assembly line. Subsequently robots are used in many applications such as industry, military, health care, search and rescue mission, deep sea and space exploration etc. Since the first use of medical robots in 1985 to conduct stereotactic brain biopsy, the growth of robotics in health care is impressive [1,2]. In healthcare robotics five themes are identified in [3]: (a) robot assisted preventive therapies and diagnosis; (b) robotic assistive technology; (c) robots supporting professional care; (d) robotics for rehabilitation treatment; (e) robotics for medical interventions. This paper reviews (e) and part of (a) i.e. robotics for medical interventions and diagnosis which are minimally invasive. This paper aims to review the state-of-the-art of minimally invasive diagnosis and interventions (e.g. surgery, biopsy), to identify the challenges in this field, to find the current trends and to provide guidance for future research.

The contributions of the paper are (i) identifying the key needs and challenges of medical robots (Section 2); (ii) comparing the external large robots and in vivo miniature robots based on key features (Table 1); (iii) presenting major external large robots with important aspects (Section 4); (iv) classifying the miniature in vivo laparoscopic robots, describing them with critical details and comparing them based on crucial characteristics (Section 5); (v) classifying the miniature in vivo endoscopic robots, describing them with critical details, comparing them based on significant characteristics and analyzing their advantages and disadvantages (Section 6); and (vi) providing the future directions of external large robots and miniature in vivo robots (Section 7).

This paper is structured as below. Section 2 provides the needs and challenges of medical robots; Section 2.2 provides challenges of external large robots, miniature in vivo laparoscopic robots and miniature in vivo endoscopic robots individually. Section 3 presents the classification of minimally invasive diagnosis and intervention robots based on size and purpose; Section 4 provides the background of external large surgery robots and reviews the major

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**Table 1**
Comparison of minimally invasive diagnosis and intervention robots based on key features.

| Robot/criteria | External large robot [15,16,35]  | Miniature in vivo robot | |
|---|---|---|---|
| | | In vivo endoscopic robot [13,19]  | In vivo laparoscopic robot [10,17,9]  |
| Operating anatomy | Any | Gastro-intestinal track | Abdominal cavity, thoracic cavity |
| Clinical applications | Surgery: general, cardiothoracic, orthopedic, neuro gynaecologic etc. | Diagnosis, biopsy | Surgery assistant: vision, task, biopsy |
| Robot position | Outside patient's body | Inside patient's body | Inside patient's body |
| Size | Large robot having multiple robotic hands | Miniature – typical diameter <20 mm and length <50 mm e.g. in [13] diameter: 11 mm, length: 25 mm | Miniature – typical diameter <20 mm and length <100 mm, e.g. in [9] diameter: 15 mm and length: 85 mm |
| Large operating room | Requires | Internal propulsions do not require,external propulsions may require | Magnetic drive may require, other propulsions do not require |
| Currently operating | Medical and research labs | Research labs | Research labs |
| Power | Mains cable | Battery, tethered | Tethered |

large robots developed primarily for robot-assisted surgery; Section 5 provides the background of miniature robots for laparoscopic assistance and reviews the robots designed and built for this purpose; Section 6 provides the background of miniature in vivo endoscopic robots and reviews the robots designed and built to provide propulsion capability to conventional capsule endoscope and, finally Section 7 provides conclusions and future trends.

## 2. Needs and challenges of medical robots

### 2.1. Needs of medical robots

Robotics for healthcare is defined as the systems capable of doing mechatronic actions based on the analysis of sensor information to provide healthcare such as to perform medical diagnosis and interventions, to deliver treatments, to support rehabilitation, to support patients in prevention programs etc. The requirements and needs of medical robots can be seen from the viewpoints of various stakeholders namely the patients, the professional users (e.g. doctors, nurses), cure and care institutions (e.g. hospitals), insurance companies, researchers etc. The needs are provided below [2–5]:

1. *Safety*: From the patient point of view safety is the most important requirement. Healthcare professionals (e.g. doctors, nurses) are keen to maintain safety because of their obligation towards the patients and also to maintain their reputation. Thus the procedures performed by the robots or with the help of robots need to be safe for the patient and the healthcare professionals. Medical robots offer newer, better and safer treatments compared to the traditional approaches in many procedures.
2. *Quality*: Care institutions and medical professionals are interested in improving the quality of diagnosis and treatments. Medical robots can help in improving quality of treatments.
3. *Accuracy and consistency*: Medical robots can perform the surgical procedures with precise geometric accuracy. It is consistent, untiring and stable while performing the surgery.
4. *Medical care in remote areas and disaster scenarios*: Robots can enable access to medical care in remote areas, space missions, undersea or underground environment and disaster scenarios where medical facilities are not available. A light-weight, flexible and modular co-operative semiautonomous robot-team can be carried to the above-mentioned environment and can be tele-operated by surgeons remotely.
5. *Enhanced documentation*: Robot assisted procedures have enhanced capability to log more detailed information about each individual case than the conventional procedures. This enables easy performance analysis and contributes to the future developments.
6. *Minimally invasive procedure*: Some traditional medical procedures (e.g. probe endoscopy) and treatments are painful and burdensome to the patients. Thus medical robots which introduce minimally invasive procedure are being adopted by the hospitals and doctors.
7. *Efficiency*: Some governments and countries are interested to make the cure and care institutions more efficient. Some medical procedures using a robot system are more efficient compared to the traditional approach. Thus by adopting medical robots care institutions can improve efficiency.
8. *Quick recovery*: Quick recovery is one of the important requirements for both the patients and the healthcare professionals. By using minimally invasive and efficient robot systems in medical procedures quicker recovery is possible.
9. *Cheaper healthcare cost*: To make the healthcare accessible to the people of all social classes, healthcare cost should go down. Though the initial cost for many robot systems are quite high, the added benefits such as the efficient operation, quick recovery time and less hospital stay may make the overall cost of healthcare cheaper.
10. *Inaccessible environment*: Medical robots enable the healthcare professionals to perform medical procedures in inaccessible areas inside the patient without major incisions.
11. *Independent living*: Patients such as disabled people and elderly wants to live an independent life. Robot systems can assist them to perform their daily activities independently.
12. *Social participation*: Social participation of disabled people and elderly are hampered in many cases due to lack of mobility and communication. Robot systems can help in improving their mobility and communication.
13. *Ageing population*: Because of the post-world war II baby boom the aged population percentage will increase next two to three