Acta Scientific COMPUTER SCIENCES

Volume 3 Issue 7 July 2021

Review Article

Augmentation of the Robotic Arm with Feedback Control

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Received: April 26, 2021

Published: June 23, 2021

Abstract

The robotic arm which has been used extensively for industrial and research applications has also been applied in precision robotic applications. The addition of a further degree of freedom at the wrist gives a superior advantage over the surgeon's hand, The added capability is of immense importance in various delicate procedures. At present most robotic grippers rely on remote human control, where errors due to overshoot, tolerance, and actuation delay can occur. Visual feedback may correct for such inherent machine and human errors. AI and neural networks with human oversight may provide more precise guidance to the robot end piece for medical and other applications. The state of the art is outlined.

Keywords: Ergonomics; Feedback Control; Artificial Intelligence; RTM

Introduction

Overview

Today, many manual tasks have been taken over by assembly-line robots. The productivity and cost of energy use for such machines will contribute to the total bills. While many studies have been performed on Human efficiency and incentives, ergonomics, and productivity [1,2], far less attention has been given to the same action done by robots. The use of robots in medical applications is less well known to Engineers. Several applications where robots are being used in Medicine are given in [3]. The UMI system (Ultrasound guided Instrument) developed at the U. of Tokyo uses an image-guided real-time orientation for needle positioning. This is a 2 dof insertion system. Another application is the LPR (light pressure robot) developed at U of Grenoble, where a 5 dof system is used for positioning and orienting a needle, with 1 d.o.f for insertion of needle (gripper), having an accuracy of 1degree in rotation and 5% for displacement. The CTBOT automatically self-calibrates on a predefined trajectory with the help of stereoscopic markers in a single CT operation. Force feedback during teleoperations is performed during insertion and translation for biopsy and insertion of Iodine seed markers. In the field of ophthalmic surgery, a robotic manipulator is described by Mulgaonkar., *et al*. [4], where two parallel X-Y stages can maintain a fixed point of rotation at the surface of the eye, reducing trauma during surgery. The prototype was designed to function with a da Vinci surgical system for gross positioning. This combination then consists of separate robotic instruments. The ”Cyberknife” robotic method with MRI guidance, described in [5] uses high-intensity focused ultrasound for ablation of interecerebral tumours. As a rule, Medical robots should not occupy large volumes of space, be robust (failsafe), and be cost-effective [6]. The advent of neural network algorithms and AI has given more capability to autonomous medical robots. However, most of the published work remains concerned with supervised medical robots. Some recent work refers to vision guidance [7], in nephroureterectomy [8], augmented reality assisted robots for thyroid surgery [9]. Home health care robots are described in [10].

In the area of controls, Fuzzy logic and Hybrid Grey prediction algorithms for laparoscopic surgical robots are mentioned in [11]. Sliding mode control of online robots for surgery is also described [12]. Virtual reality and mixed virtual reality for video and robot-assisted thoracic operations are mentioned in [13]. Robots are also being used by the military and police for bomb disposal, nuclear operations, and also archaeological explorations. The proto-types for robotic surgery used the PUMA arm and began in 1985 where the PUMA 360 arm was used [14] to perform surgical procedures. Subsequently, PRODOC and ROBODOC developed. An adaptation of the 5 d.o.f robot arm is given in [15] where bio-signals from sensors control the robot. The innovation bypasses the use of muscular movements which control a robot in the traditional sense.

Control

Feedback by visual transducers has been investigated in [7]. Feedback could be optical or pressure-dependent (piezoelectric) and has been achieved for MRI-guided prostate percutaneous therapy described by [16], Su [18]. In cases where control has to be performed across a barrier, magnetic activation has been applied by [19], as a strategy to transmit actuation forces across a physical barrier. Haptic control may now be possible with the advent of 5G networks making it truly feasible to conduct remote surgical maneuvers. Lack of haptic feedback is cited as a major disadvantage for novice surgeons by [20]. An optical technique using stress-induced Moire fringes in endoscopy is described in [21]. Simulation by virtual and augmented reality is described by [22]. The quantification of error by the control and feedback can be represented by a confusion matrix, where false positives, false negatives, and true positives or negatives are calculable [7]. Positioning accuracy for brain surgery was looked at [14], where absolute positioning accuracy is of importance. Similarly in Laparoscopy, the hybrid grey model has been applied for auto-tracking algorithms [11].

The need for feedback

A major drawback of robot-assisted surgical procedures is the lack of tactile and haptic feedback to assess the forces developed and applied at the operating area. In delicate procedures, excessive force can damage the nerves or tissue being worked on. Several methods have been developed to get around this difficulty. Some use visual feedback for depth perception [22], and environmental feedback with plasticity response [23]. Another possibility would be to apply force sensors on the robotic tool with algorithms for generating feedback. This would need to be coupled with visual feedback. In the particularly delicate cases where absolute precision and delicacy are required, it may not be possible at present to dispense with an experienced surgeon.

Augmentation with AI

The development of Artificial intelligence coupled with neural networks that constantly update and thus modify the knowledge base gives an added edge to the technology of robotics. The robot tool is no longer an extension of the human operator but can also modify and correct commands received by it. Some works have appeared in various applications using visual feedback. The end tool can be either rotated (6^{th} d.o.f) or moved linearly without rotation, using a maximum of 5 d.o.f. The Scott Russell mechanism can be used for 3 dof Cartesian motion for cannulisation. Haptic feedback has been applied for the maxilla The end tool can be either rotated (6^{th} d.o.f) or moved linearly without rotation, using a maximum of 5 d.o.f.

A study was performed at MIT on the Phantom OMNI, a haptic robot for touching and feeling 3 D data. There are 6 joints, where the first three are used for positioning the end gripper, and the remaining three for finding orientation. Using inverse kinematics, it was shown that there are 8 orientations for an end position. Knowing the constraints one can choose the most desirable orientation. The OMNI was programmed with the C++ language, Beckmann [24]. Spatial constraints such as a line, circle, cylinders, spheres, and Bezier curves were illustrated.

Minimal movement trajectories

Several papers [22-25] have appeared to stress the importance of inverse kinematics and under actuation. Planning the trajectory by a translation and two rotations was described by [25,26]. An algorithm to calculate trajectories based on smoothness and torque constraints is developed in [27]. However, the aspect of ergonomics is not considered in light of RTM except in the calculation of energies, but not in the efficiency of motion, i.e., the least number of steps to do a task and time involved.

In [28] they have expounded on the various "primitives" and error handling in motion of specific objects, somewhat analogous to defined actions in Work-Study termed "Therbligs". Various basic movements are termed "skills" and assigned a hierarchy, which is used in the error correction algorithm. The methodology has been applied for service-type applications by them. The inverse approach is also referred to, and in [29] some inverse kinematic planners in the case of underactuated systems were cataloged. Under-actuation is one of the methods by which unnecessary movements can be avoided.

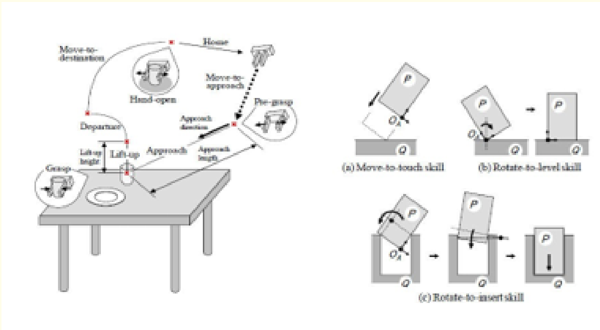

Figure 1: Various tasks involved in grip sequence [28].

Visual control of trajectory and end positioning

In the Vision-Based Approach, the object is viewed through the camera and its 2D coordinates are estimated. The tool of the arm is also mapped in the same coordinate system. Subsequently, the positional error is calculated. The method cannot estimate the depth error, and for this binocular vision, sensing is required. Some researchers have developed vision-assisted robots for various applications [7,30-32]. In the area of archaeological mapping and surveying, the 3D capability was reconstructed from sectional 2D photographs of a sunken city [33]. A possible alternative to binocular sensors would be to use one arm-mounted USB camera for X-Y or Z motion tracking. An orthogonally placed camera on the arm, or at a distance could then track the motion in the third orthogonal direction. The addition of haptic feedback would augment the coordinate-based system in cases of overshoot or excess force at the tool end. Calibration of a system for "bin picking" with 2D monocular vision was discussed [34]. In [35] also are found industrial robots with vision-based enhancement. In Fuzzy Based Processing, a logic-based approach using fuzzy rules is applied to correct for the error in positioning. In the usual case, a human operator uses his/her binocular vision to adjust the tool and correct for errors in position. This happens for instance in medical or nuclear handling of the tool. However, in bomb disposal or archaeological explorations, the robot must be equipped with binocular vision and an AI-driven set of rules to proceed with success. A representative description of the fuzzy logic approach is shown in [36].

Conclusion

Autonomous self-control remains a distant vision yet to be realized, especially in the critical areas of medical care, invasive surgical procedures, and space exploration beyond the reach of normal communication. It remains to be seen if the rapid spurts in information and mobile technology are matched with similar gains in robotic control, or perhaps if the two can be coupled shortly.

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Volume 3 Issue 7 July 2021