Robotic Palpation Modeling for KUKA LBR IIWA Using Gazebo Simulator

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http://kpfu.ru/robolab.html

Abstract

Palpation is one of diagnostic methods being extensively used in medical practice. It is often used for tumor detection in cancer screening but its efficacy is highly dependent on examining physician's skill. Therefore, using a robotic tool could make this procedure more objective. In this paper, we present our control and perception modules of autonomous palpation robotic system. We have modeled KUKA LBR IIWA manipulator control using MoveIt motion planning in Robot Operating System and validated it in Gazebo simulator.

Keywords: robotic palpation, autonomous palpation simulation, surface traversing, medical robotics.

1. Introduction

Surgical palpation is an examination of a patient's body technique that is performed manually by a practitioner with his/her hands, which helps to decide on a diagnosis by analyzing obtained tactile information[1]. Palpation is commonly used in diagnosing of atherosclerosis, hypersplenism, thrombophlebitis and many other diseases and illnesses. One of the most significant areas where palpation is being used is an early cancer diagnosis that requires deciding on whether there is a tumor in examined body part according to tissue's relative stiffness; and, if possible, identifying its type[1].

The main reason why automation of a palpation procedure is an important and necessary task is its subjectivity, since it is strongly dependent on practitioner's capability of sensing slightest changes in stiffness that is followed by interpretations of these tactile sensations. Those skills could not be easily taught as tactile perception is very individual. Main goals of our research is to allow compensation of the aforementioned subjectivity by quantitative estimation of palpated tissues' and detected tumors' properties, which could increase a percentage of correct abnormalities detection and enhance a spatial measurement‘s accuracy.

In this paper we present a simulation of a palpation procedure being performed with a help of an autonomous robotic manipulator. Simulation makes possible to analyze the robot's behavior within the palpation procedure before performing real world experiments and help identifying weaknesses of the developed algorithm, its software implementation and the robot hardware[2]. Simulation is performed in Gazebo simulator[3] that provides necessary modules to verify algorithms, estimate sensors' performance and control multiple physical properties of different simulated objects[4,5].

2. Related Work

Though robotic palpation researches lack works that are directly related to simulation, still there is a variety of papers that are focused on automated and robotized methods of surface exploration and tissue properties acquisition in medical purposes.

There exist different ways of robot end-effector interaction with a surface being examined. Garg et al.[6] have applied indentation technique, which is one of the most simple and frequently used methods in robotic palpation research. Guo et al.[7] have introduced indentation with a static measurement, i.e. when a robot keeps an end-effector position at a certain indentation depth until sensor's data becomes stable, thus leading to uncertainties reduction. On the other hand, Liu et al.[8] implemented continuous rolling across an examined surface that was compared with the indentation technique results and demonstrated faster surface exploration with a higher density of extracted surface information. Goldman et al.[9] used continuous cycloid motions to compensate a bias that was influenced by a direction of movements across an examined surface. Chalasani et al.[10] proposed using a continuous motion across an examined surface with sinusoidal depth profiles, referencing technique being used in a traditional surgery. Konstantinova et. al.[11] introduced an indentation method that applied a technique of coupled normal and lateral forces modulation that was based on mathematical model that had been derived from manual palpation experiments.

Surface exploration strategy is a complementary problem being addressed by a robotic palpation research. Goldman et al.[9] applied a kernel search algorithm that generates a projection on a surface grid with an adaptive resolution. In Refs. 12 and 13 authors used a force feedback from force/torque sensors in order to compute normal and tangential forces to generate desirable end-effector position and orientation in a way that follows the normal of a palpated surface. Hess et al.[14] used representation of a surface exploration task as a traveling salesman problem and have used Kinect camera for extraction of a surface information in a graph generation. In Refs. 6 and 10 the authors applied machine learning techniques to help in a generation of trajectories for a surface exploration.

Some of the aforementioned researches have elements that use a finite element simulation to estimate a surface behavior; however, once an algorithm is being integrated into a robotic system, the simulation becomes computationally expensive.

This paper aims to provide a simulation setup for robotic palpation to be performed by KUKA LBR IIWA manipulator. Similar model has proven to be an appropriate choice for a surface exploration by Virga et. al.[15] who have used it for an autonomous ultrasound screening robotic system.

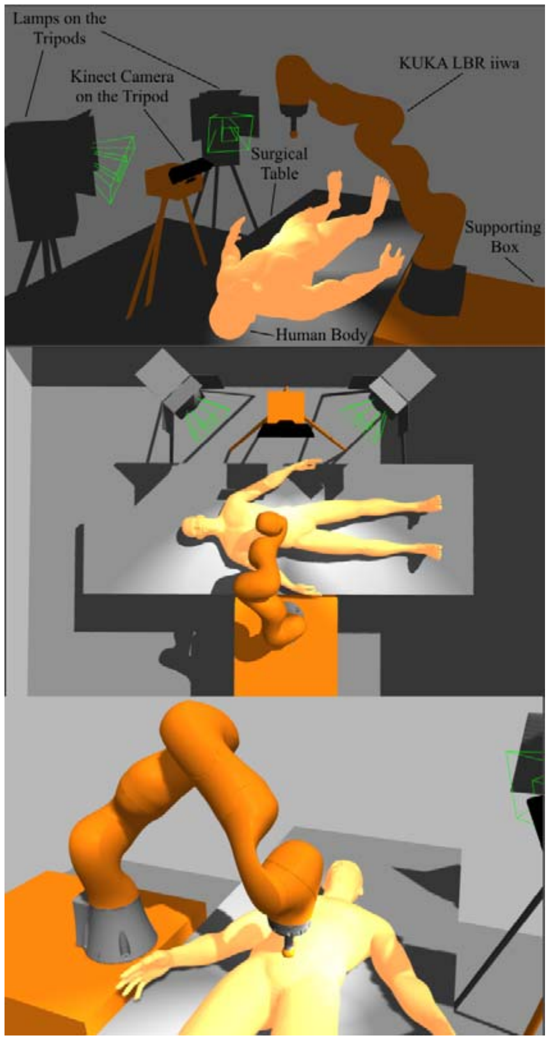

Fig. 1. Simulation scene.

3. Setup

Simulation setup is depicted in Fig. 1 and consists of a robotic manipulator that performs palpation task, clinical setting that includes auxiliary systems and an object of palpation procedure, which is a virtual patient.

3.1. *Simulation setup*

To implement a palpation procedure in a simulation we used KUKA LBR IIWA manipulator model[16]. Packages provide the model that fully supports Gazebo simulator with a full MoveIt! integration, which makes it possible to implement the control for a robot via Robot Operating System (ROS).

KUKA LBR IIWA robot is a 7 degrees of freedom lightweight redundant manipulator that was developed for a human-robot collaboration (HRC). Manipulator's redundancy as it have been pointed out by a Torabi et. al.[17] results in decreased inertia and friction during palpation procedures. HRC-compatibility is also an important feature of KUKA LBR IIWA manipulator as such robotic systems are developed to assist physician in the first place. The model was extended by adding a spherical indenter as an end-effector for a palpation, which is connected with a force sensor in the seventh link of the original manipulator. Similar types of end-effectors were used in Refs 6, 7, 9 and 11.

3.2. *Clinical setting*

Models for clinical setting were either developed specifically for this task (the surgical table, the tripod, the lamp models), or taken from default Gazebo simulator repositories (Kinect camera and the box).

Clinical setting consists of a surgical table on which a palpated object is to be placed, a rectangular box on which a robotic manipulator is mounted in a such way that its workspace covers most of the surgical table area, Kinect camera with ROS depth camera plugin[18, 19] to estimate surface geometry before palpation procedure starts and two lamps for better illumination. In order to be directed towards an palpated object, lamps and Kinect camera are mounted on tripods. Kinect camera and lamps are directed towards an abdominal area of a human body model - this area will be examined during the autonomous palpation process.

3.3. *Virtual patient*

A 3D model of virtual patient was obtained from Ref. 20 as an OBJ 3D model and then converted into STL format in order to be applied in Gazebo simulator. However at the current stage of development it serves only as a visual part of a virtual patient - in terms of collision virtual patient is a rectangular box, which surface is palpated.

4. Autonomous Palpation

There are two aspects of autonomous palpation: control, i.e., making a manipulator's end-effector traverse the target surface, and perception, i.e., getting data from manipulator's sensors. These aspects are further described in this section.

4.1. *Control*

Sliding movement across the palpated surface in a snake scan manner was implemented for examination of a surface with predefined position and dimensions. Prior to surface examination the manipulator moves slowly in a free space towards the palpation surface until the end-effector detects a collision with the surface.

4.2. *Perception*

Once manipulator's end-effector is in contact with the surface, z-component of force measurements from 3-axis force/torque sensor, which is embedded into 7-th robot's link, increases tenfold. This allows detecting a contact during movement towards the surface. To ensure consistent sensing, the end-effector is kept at the orientation that is orthogonal to the examined surface while running the palpation procedure.

During the palpation procedure data from the sensor is being encoded into a marker message and is published as a topic. From there these data may be fetched and visualized via RViz, which is a 3D visualizer for ROS framework. Thus it is possible to obtain a color-coded map of normal force values for each examined point of the palpated surface. This feature provides the ability to detect simulated abnormalities of an examined tissues.

5. Discussion and Future Work

This paper presented our first version of an open source software that contains KUKA LBR IIWA extended model and a simulation scene. Our software allows testing robotic palpation algorithms. Additionally one of the basic palpation methods, which consists of a surface traversing and data acquisition, was implemented and successfully tested in the proposed simulated environment.

Our future work is aimed at making simulated palpation procedure more general-purposed. That includes implementation of a surface geometry information acquisition by Kinect camera and subsequent support of a curved surface palpation without predefining the position and dimensions of a target object. Another goal is set at expanding the available palpation methods by implementing new ones. Finally, we plan to introduce a tissue model that possesses elastic properties so that a force sensor could react differently to surfaces with various elasticity characteristics.

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References

1. J. L. Longe and D. S. Blanchfield, *Gale encyclopedia of medicine*, 2nd edn. (Detroit, MI: Gale Group, Detroit, MI, 2002).
2. Sagitov, A., Li, H., Magid, E. Toward automated open wound suturing using haptic feedback: detecting wounds and planning the suture. In *Int. Conf. on Artificial Life and Robotics* (2018), pp. 208-211.
3. Sagitov, A., Li, H., Schiefermeier-Mach, N., Magid, E. Extending Gazebo simulator for surgical robotics: tissue and suture modeling. *International Conference on Artificial Life and Robotics* (2019), pp. 124-127.
4. Lavrenov, R., Zakiev, A. Tool for 3D Gazebo map construction from arbitrary images and laser scans. *International Conference on Developments in eSystems Engineering* (IEEE, 2017), pp. 256-261.
5. Sagitov, A., Tsoy, T., Li, H., Magid, E. Automated open wound suturing: detection and planning algorithm. *Journal of Robotics, Networking and Artificial Life*, **5(2)** (2018), pp.144-148.
6. A. Garg, S. Sen R. Kapadia, Y. Jen, S. McKinley, L. Miller and K. Goldberg, Tumor localization using automated palpation with Gaussian process adaptive sampling, *IEEE International Conference on Automation Science and Engineering* (2016), pp. 194–200.
7. J. Guo, B. Xiao and H. Ren, Compensating Uncertainties in Force Sensing for Robotic-Assisted Palpation, *Applied Sciences*, **9(12)**: 2573 (2019).
8. H. Liu, D. P. Noonan, B. J. Challacombe, P. Dasgupta, L. D. Seneviratne and K. Althoefer, Rolling mechanical imaging for tissue abnormality localization during minimally invasive surgery, *IEEE Transactions on Biomedical Engineering*, **57(2)** (2010), pp. 404–414.
9. R. E. Goldman, A. Bajo and N. Simaan, Algorithms for autonomous exploration and estimation in compliant environments, *Robotica*, **31(01)** (2013), pp. 71–87.
10. P. Chalasani, L. Wang, R. Roy, N. Simaan, R. H. Taylor and M. Kobilarov, Concurrent nonparametric estimation of organ geometry and tissue stiffness using continuous adaptive palpation, *IEEE International Conference on Robotics and Automation* (2016), pp. 4164–4171.
11. J. Konstantinova, G. Cotugno, P. Dasgupta, K. Althoefer and T. Nanayakkara, Correction: Palpation force modulation strategies to identify hard regions in soft tissue organs, *PloS One*, **13(1)** (2018), p.e0192259
12. E. C. Li and Z. M. Li, Surface Tracking with Robot Force Control in Unknown Environment, *Advanced Materials Research*, **328-330** (2011), pp. 2140-2143.
13. J. Back, J. Bimbo, Y. Noh, L. Seneviratne, K. Althoefer and H. Liu, Control a Contact Sensing Finger for Surface Haptic Exploration, *IEEE International Conference on Robotics & Automation* (2014), pp. 2736–2741.
14. J. Hess, G. D. Tipaldi and W. Burgard, Null Space Optimization for Effective Coverage of 3D Surfaces using Redundant Manipulators, *IEEE/RSJ International Conference on Intelligent Robots and Systems* (2012), pp. 1923-1928.
15. S. Virga, O. Zettinig, M. Esposito, K. Pfister, B. Feisch, T. Neff, N. Navab and C. Hennersperger, Automatic force-compliant robotic ultrasound screening of abdominal aortic aneurysms, *IEEE/RSJ International Conference on Intelligent Robots and Systems* (2016), pp. 508-513.
16. C. Hennersperger, B. Fuerst, S. Virga, O. Zettinig, B. Frisch, T. Neff and N. Navab, Towards MRI-based autonomous robotic US acquisitions: a first feasibility study, *IEEE transactions on medical imaging*, **36(2)** (2017), pp. 538-548.
17. A. Torabi, M. Khadem, K. Zareinia, G. R. Sutherland and M. Tavakoli, Application of a Redundant Haptic Interface in Enhancing Soft-Tissue Stiffness Discrimination, *IEEE Robotics and Automation Letters* **4(2)** (2019), pp. 1037–1044.
18. Safin, R., Lavrenov, R. Implementation of ROS package for simultaneous video streaming from several different cameras, *International Conference on Artificial Life and Robotics* (2018), pp. 220-223.
19. Safin, R., Lavrenov, R., Martínez-García, E. A., & Magid, E. ROS-based Multiple Cameras Video Streaming for a Teleoperation Interface of a Crawler Robot. *Journal of Robotics, Networking and Artificial Life* **5(3)** (2018), pp.184-189.
20. free3d.com, (2015). *Male Base Mesh 3D Model*. [online] Available at: free3d.com https://free3d.com/3d-model/male-base-mesh-6682.html [Accessed 13 Dec. 2019].