# Vision-based autonomous navigation for medical examination using a UR3e manipulator

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**Abstract**

Medical robotics is an emerging field of robotics within a healthcare sector. This interdisciplinary field focuses on prototyping, building and developing advanced robots for numerous clinical application. Modern robotic technologies have a tremendous potential for performing medical examination procedures such as ultrasonography using robotic manipulators that act in an autonomous manner. A manipulator navigation plays a key role in a safe and efficient exploration of a human body. This paper presents a development of a vision-based autonomous navigation system for a 6-DOF UR3e robotic arm. The developed system is based on a 3D point cloud and uses MoveIt for path planning. Gazebo was used as a simulation framework to validate the navigation system.

*Keywords*: Medical robotics, Manipulator, Autonomous navigation, ROS, MoveIt, Gazebo

## 1. Introduction

The healthcare industry has been making a notable progress in recent years with an advancement of robotics technologies [1], [2]. Due to COVID-19 pandemic an automation of medical procedures employing robotics technologies became critical [3], [4]. Robots are progressively being employed for a broad spectrum of tasks that include surgery [5], rehabilitation [6], diagnostics [7], and drug delivery [8], offering precision, efficiency and remote operational capabilities [9]. Modern robotic technologies have a tremendous potential for performing medical examination procedures using robotic manipulators [10] that employ various end-effectors to provide additional functionalities within specific tasks. Nowadays, robotic arms became a major focus for medical research groups [11]. Robotic manipulators feature a lightweight reconfigurable arm design, high precision actuators and motion control systems. These robots are used in medical scenarios that require a high degree of precision and quality of a task performance, e.g., tissue suturing [12], minimally invasive surgery [13], [14], and ultrasonography [15].

An autonomy enables an unskilled human worker to easily configure a robotic system in a setup phase before performing a medical procedure. Autonomous manipulators execute tasks consistently without a variability that can be introduced by human operators [16]. This consistency is crucial in medical examination scenarios where uniformity is essential. Manipulator navigation plays a key role in a safe and efficient autonomous exploration of a human body [17]. The exploration refers to autonomously move, position, and control a trajectory of a manipulator within a designated space. Vision-based manipulator navigation is an approach of guiding and controlling a robotic manipulator's movement using visual information. A robotic system relies on cameras or other vision sensors to perceive and interpret an environment [18].

This paper presents a development of a vision-based autonomous navigation system for medical examination using a 6 degrees of freedom (DoF) UR3e robotic arm. The developed system is based on 3D point cloud data. 3D point clouds are produced by a depth camera, which measure physical dimensions of a human body. MoveIt package [19] was used for motion planning, manipulation, and control of the robotic arm. Gazebo [20] was used as a simulation framework to validate the navigation system.

## 2. System setup

A UR3e manipulator (Fig. 1, left), manufactured by Universal Robots, stands as a suitable robotic system for automating low-weight processing tasks. The capability to grab and move a medical tool is facilitated by its payload capacity of 3 kg, providing a sufficient control to navigate an end-effector. Flexible motion planning is achieved using the UR3e arm's capability for 360 degrees of rotation in all its joints. For a virtual robot setup a ROS-based UR3/UR3e controller with simulation in Gazebo was used (Fig. 1, right).

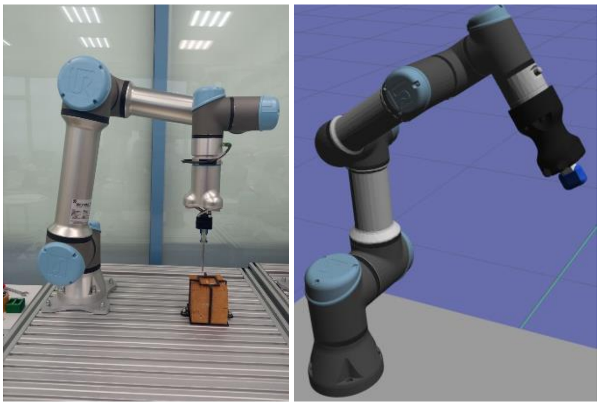

Fig. 1. UR3e robotic arm: a real robot (left) and a virtual manipulator model (right)

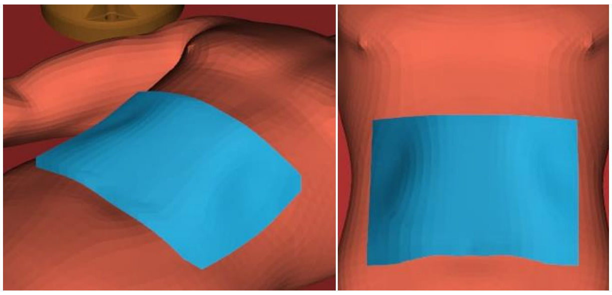

Fig. 2. Depth data: a 3D point cloud (blue) of a region of interest

A depth sensor is a type of imaging device that captures depth data along with visual data. Unlike traditional cameras that record color and intensity information, depth cameras provide additional details about a distance from a camera to an object. In a Gazebo simulation environment, integrating a Kinect camera model involves configuring a depth camera plugin. ROS/Gazebo provides a package *gazebo_ros_pkgs* that contains wrappers and tools for using ROS with Gazebo. The package includes *gazebo_ros_openni_kinect* plugin that serves as a driver for interfacing a Kinect camera with Gazebo simulation framework. The Gazebo camera plugin publishes depth data on a ROS topic of type *sensor_msgs/Image*. Depth data captured by the virtual Kinect camera is used by a 3D point cloud processing module. Fig. 2 shows a 3D point cloud of an abdomen.

A simulation environment in Gazebo contains a UR3e manipulator model. UR3e is mounted on a supporting base that allows to effectively cover a table used for examinations. The Kinect camera model with a depth camera plugin captures visual and depth data of a human body. A human body model is placed on the examination table within the manipulator workspace and the Kinect camera range. UR3e is equipped with a transducer device used as an end-effector. The virtual environment is depicted in Fig. 3.

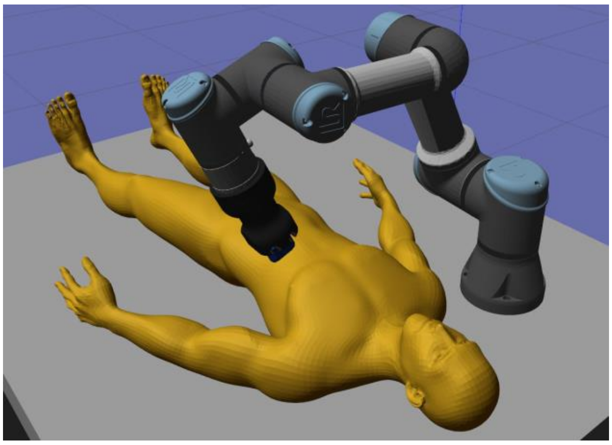

Fig. 3. Gazebo environment: a human, an examination table and UR3e manipulator, that explores a chest.

## 3. Navigation

A proposed navigation system consists of three modules: a 3D point cloud processing, a path planning and a motion planning. The first module serves as a foundation for a spatial perception. The second module, which is responsible for waypoint generation, takes the processed point cloud data and calculates series of feasible waypoints for navigation. The third module focuses on translating the planned paths into executable motion commands for the manipulator.

A point cloud is a collection of data points defined by their coordinates in 3D space. Each point represents a specific position in an environment and may include additional information, such as color or intensity. The module processes raw 3D point cloud data obtained from the depth camera. This step involves filtering input depth data and removing invalid points. Point Cloud Library (PCL) library [21] was utilized to process raw 3D point cloud data and create a digital representation of a human body’s specific region of interest.

Waypoint generation determines a set of points that represents a desired path for the manipulator. The module is responsible for generating waypoints and utilizes the processed 3D point cloud model as an input. Normal vectors of points are employed to calculate a rotation matrix for the end-effector. The output is a sequence of feasible waypoints for motion planning (Fig. 4, bottom).

A motion planning process involves converting a trajectory into a series of motion commands. The motion planning module uses MoveIt framework to plan a motion for the robotic system, validate it and then execute the motion plan (Fig. 4, top). MoveIt uses inverse kinematics solvers for determining joint configurations and collision checking to ensure safe motion of UR3e.

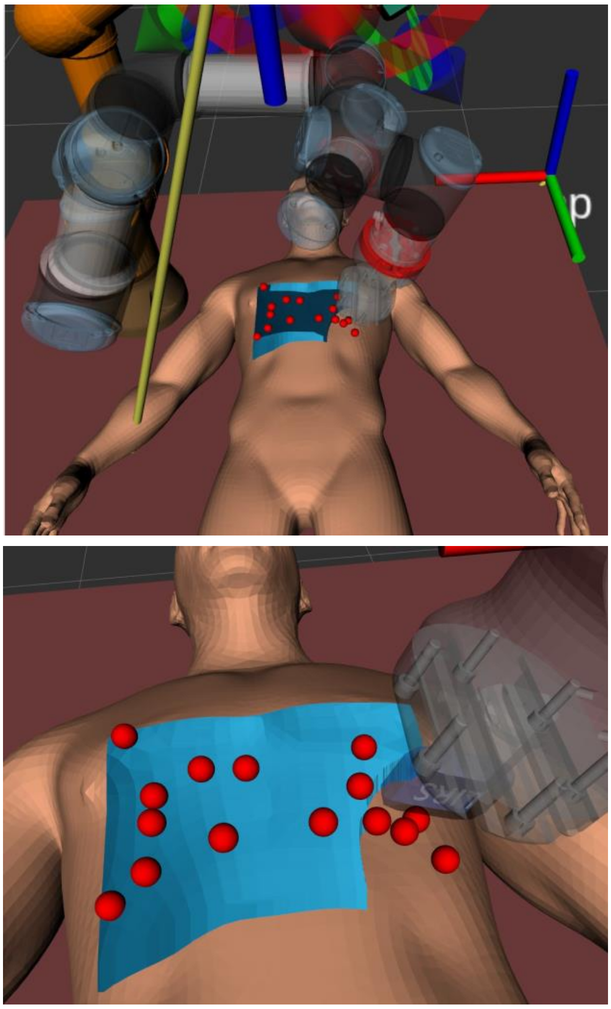

Fig. 4. Navigation in RViz: red markers denote waypoints that MoveIt uses for motion planning

RViz software [22] is commonly used together with MoveIt for visualization of motion planning tasks. A control ROS node is written to bring up the autonomous navigation system and start path planning.

## 4. Conclusions

This paper presented a vision-based autonomous navigation system for medical examination using a 6-DOF UR3e robotic arm. The developed system relies on depth-sensing cameras and utilizes a 3D point cloud. MoveIt motion planning framework was used for path planning and control of the robotic arm. The validation of the developed navigation system was conducted in Gazebo simulation framework. As a part of our future work, we plan to validate the proposed navigation system on a real UR3e robot. To achieve this, we will use a real Kinect depth camera and a human mannequin.

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