A New Robotic Application for COVID-19 Specimen Collection Process

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***Abstract*—Covid-19 manual specimen collection process is too critical for health care workers due to they are able to getting infection from Covid-19-patient during the medical interaction. The purpose of this study, a novel robotic application is developed to achieve automatic specimen collection process for new corona virus (COVID-19). This application is a protection tool for health care workers for the Covid-19 pandemic. This robotic application easily and safely complete the sampling process task and assist to health care workers to prevent infection. The application is basically consist of a collaborative robot (COBOT), base plate, fixtures and a gripper. There are co-operation activities between the COBOT and health care worker to complete all tasks. The robotic application has been tested in the plant health care center as a prototype. The cycle-time (192 sec) for the robotic process needs to be improved. The Manual process is still %60 faster than robotic application. The biggest challenge in this application is patient's mouth and nose physical size changes. Robot movements for the specimen collection in nose and mouth are arranged just based on the fixed point. This needs to be improved according to size changes. Covid-19 specimen collection process with a robotic application has been presented which don't need any health care worker interaction with patient. This application needs to be improved related with above challenges to make a shelf product. It will create valuable impact and save lives in this pandemic.**

***Keywords*—Covid-19; Cobot; Robot; Safety; Kinematic**

I. INTRODUCTION

COVID-19 has now become a pandemic in the world [1], [2]. The new coronavirus has affected almost all countries which is shown in Fig. 1 reported by WHO (World Health Organization) [3]–[7]. Worldwide interconnected all countries affected by this pandemic [8]–[10].

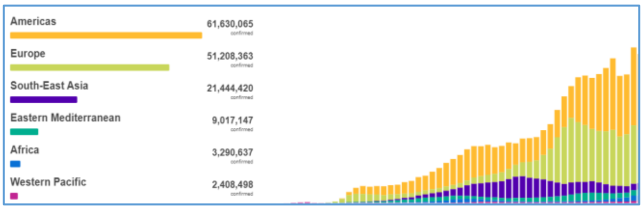

Fig. 1. WHO Covid-19 report

Therefore, global efforts are needed to break the chains of virus infections [8], [9]. There are many robotic assistance applications and automation systems in healthcare services [11]–[14]. Recently, also industrial robots usage in medicine have been increasing [7-11]. It is declared in WHO announcement that health care workers are at the front line of the COVID-19 outbreak response and as such are exposed to hazards that put them at risk of infection. The aim of this study to create a novel robotic application for doing fully automatically sampling process for New Corona Virus (COVID-19) [15]–[18]. This application makes possible to complete covid-19 sampling test without the any medical person and reduce the high infection rate of health care workers.

II. SPECIMEN COLLECTION UNIT

Covid-19 specimen collection process is one of most critical cases for health care workers due to they are able to getting infection from Covid-19-patient during the medical interaction [19]–[22]. Therefore, a robotic application shown in Fig. 2 designed to protect health care workers during the medical interaction with Covid-19 patients.

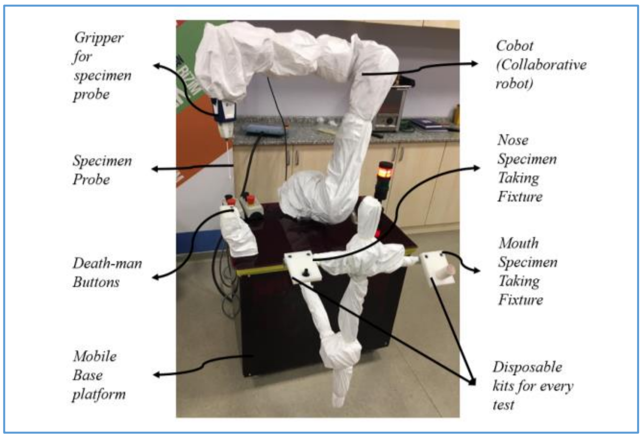

Fig. 2. Coivd-19 specimen collection unit

This robotic application basically consist of a collaborative robot, mobile base plate, fixtures (nose and mouth), disposable kits (nose and mouth) and a gripper to pick and place specimen. This robotic application has kinematic and the robot kinematic system needs to be approved to check robot capable for the process.

A. *Robot Kinematic*

Robot kinematics science [23], [24] is the relationships between the positions, velocities, and accelerations of the links of a mechanical manipulator, where a manipulator is an arm system, finger model or legs structures. Links of the robot are modelled as fix bodies and its joints are assumed to provide a rotation [25]–[28]. There are two kinematic models for industrial robots; forward and inverse kinematics [25], [26]. Forward kinematics uses the robot joint parameters to calculate the configuration of the chain, and inverse kinematics reverses this calculation to determine the joint parameters [28], [29]. Forward kinematics refers to the use of the kinematic equations of a robot to compute the position of the end-effector from specified values for the joint parameters and reverse process that calculate the joint parameters achieving a specified position of the end-effector is known as inverse kinematics [26]–[31]. In this study, we created a kinematic model based on quaternion algebra for multi robot production cell to calculate dynamic TCP for collision management. Quaternions are a number system that extends the complex numbers [29]–[31]. They were first described by Irish mathematician William Rowan Hamilton in 1843 and applied to mechanics in three-dimensional space. A feature of quaternions is that multiplication of two quaternions is noncommutative[32][33]. Hamilton defined a quaternion as the quotient of two directed lines in a three-dimensional space or equivalently as the quotient of two vectors [31], [34]–[40].

B. Robot Forward Kinematic

A quaternion can be defined as;

$$q = w + xi + yj + zk \tag{1}$$

In the equation, w, x, y and z are real number. i, j and k are used in $i^2 = j^2 = k^2 = -1$ special equation. They are the basis elements of a quaternion. A quaternion can be defined as vector as well;

$$q = [w, \vec{v}] \rightarrow q = (q_1, \vec{q}_v) \rightarrow \vec{q}_v = i\vec{q}_2 + j\vec{q}_3 + k\vec{q}_4 \tag{2}$$

Axis-angle demonstration in Fig. 3 is needed to define the industrial robot kinematic model using quaternion algebra. P is just a single axis and,

$$P = \ [\ x, y, z\ ]\ \ [\ q1, q2, q3, q4\ ]$$

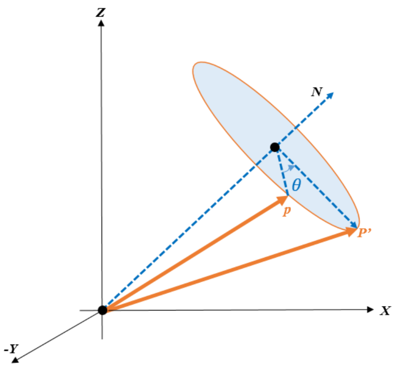

Fig. 3. Axis-angle model

where θ Rotation of the P axis is define as P', and P' can be defined with the equation below;

$$P' = R_q(P) = qPq^* = (q^2 1 - \vec{q}_v \cdot \vec{p})\vec{p} + 2q_1(\vec{q}_v \otimes \vec{p}) + 2\vec{q}(\vec{q}_v \cdot \vec{p}) \tag{3}$$

$$\begin{aligned} P'_x = \ & q_1 \cdot q_1 \cdot p_x + 2 \cdot q_3 \cdot q_1 \cdot p_z - 2 \cdot q_4 \cdot q_1 \cdot p_y + q_2 \cdot q_2 \cdot p_x \\ & + 2 \cdot q_3 \cdot q_2 \cdot p_y + 2 \cdot q_4 \cdot q_2 \cdot p_z - q_4 \cdot q_4 \cdot p_x - qh_2 \cdot q_2 \cdot p_x \end{aligned} \tag{4}$$

$$\begin{aligned} P'_y = \ & 2 \cdot q_2 \cdot q_3 \cdot p_x + q_3 \cdot q_3 \cdot p_y + 2 \cdot q_4 \cdot q_3 \cdot p_z + 2 \cdot q_1 \cdot q_4 \cdot p_x \\ & - q_4 \cdot q_4 \cdot p_y + q_1 \cdot q_1 \cdot p_y - 2 \cdot q_2 \cdot q_1 \cdot p_z - q_2 \cdot q_2 \cdot p_y \end{aligned} \tag{5}$$

$$\begin{aligned} P'_z = \ & 2 \cdot q_2 \cdot q_4 \cdot p_x + 2 \cdot q_3 \cdot q_4 \cdot p_y + q_4 \cdot q_4 \cdot p_z - 2 \cdot q_1 \cdot q_3 \cdot p_x \\ & - q_3 \cdot q_3 \cdot p_z + 2 \cdot q_1 \cdot q_2 \cdot p_y - q_2 \cdot q_2 \cdot p_z + q_1 \cdot q_1 \cdot p_z \end{aligned} \tag{6}$$

Below equation is defined for multi axis and serial link (d) of robots.

$$f\ (d_{link}, Q, d_{ofset}) = q \cdot \vec{d}_{link} \cdot q* + \vec{d}_{ofset} \tag{7}$$

$$P_{n\,(x,y,z)} = (Q_n \cdot Q_{n-1\ldots0}) \cdot D_n \cdot (Q_n \cdot Q_{n-1\ldots0})^* + P_{n-1(x,y,z)} \tag{8}$$

C. Robot Inverse Kinematic

The conversion of the position and orientation of a manipulator end-effector from Cartesian space to joint space is called the inverse kinematics problem. If the position and rotation defined as $U = ({}^0P_6,\ Q_{123456})$, the inverse kinematic can be written below equations. 6 DOF robot’s axis 3-4-5 positions are always same but rotations are different. Thus, P3’s position (x, y, and z) is;

$${}^0P_3 = {}^0P_4 = {}^0P5 = P_{6(x,y,z)} - (Q_d{}^* \cdot Q_{123456}) \cdot D_n \cdot (Q_d{}^* \cdot Q_{123456})^* \tag{9}$$

The angle for each axis is;

Axis-1 (θ_1): Below equations are needed to define the angle of axis-1’ angle.

$$\theta_1 = 2 \cdot a\tan\left(\frac{-P_{3x} \pm \sqrt{P_{3x}{}^2 + P_{3y}{}^2 - (d_{1y} + d_{2y} + d_{3y})^2}}{P_{3y} + (d_{1y} + d_{2y} + d_{3y})}\right) \tag{10}$$

There are 4 different solutions can be created for axis-1 angle. *Axis-3 (θ_3):* Below equations needed for defined axis-3’ angle.

$$m_1 = \left(P_{3x} + \frac{Sin\left(\theta_1 \cdot \frac{\pi}{180}\right) \cdot (d_{1y} + d_{2y} + d_{3y})}{Cos\left(\theta_1 \cdot \frac{\pi}{180}\right)} \right) - d_{1x} \tag{11}$$

$$m_2 = (P_{3z} - d_{1z})\ ,\ m_3 = ((d_{2x} \cdot d_{3x}) + (d_{2z} \cdot d_{3x}))$$

$$m_4 = ((d_{2x} \cdot d_{3z}) - (d_{2z} \cdot d_{3x})) \tag{12}$$

$$m_5 = \frac{(m_1{}^2 + m_2{}^2 - (d_{2x}{}^2 + d_{2z}{}^2 + d_{3x}{}^2 + d_{3z}{}^2))}{2} \tag{13}$$

$$a = m_3 + m_5, \quad b = -2 \cdot m_4, \quad c = m_5 - m_3 \tag{14}$$

$$\theta_3 = 2 \cdot a\tan\left(\frac{-b \pm \sqrt{b^2 - 4 \cdot a \cdot c}}{2 \cdot a}\right) \cdot \frac{180}{\pi} \tag{15}$$

16 different solutions can be created for axis-3 angle. *Axis-2 (θ_2):* Below equations needed for defined axis-3’ angle.

$$n_1 = d_{2x} + Cos\left(\theta_3 \cdot \frac{\pi}{180}\right) \cdot d_{3x} + Sin\left(\theta_3 \cdot \frac{\pi}{180}\right) \cdot d_{3z} \tag{16}$$

$$n_2 = d_{2z} - Sin\left(\theta_3 \cdot \frac{\pi}{180}\right) \cdot d_{3x} + Cos\left(\theta_3 \cdot \frac{\pi}{180}\right) \cdot d_{3z} \quad (17)$$

$$n_3 = (P_{3z} - d_{1z}) \;, \quad a_2 = n_2 + n_3 \;,$$

$$b_2 = 2 \cdot n_1 \;, c_2 = n_3 - n_2 \quad (18)$$

$$\theta_2 = 2 \cdot a\tan\left(\frac{-b_2 \pm \sqrt{{b_2}^2 - 4 \cdot a_2 \cdot c_2}}{2 \cdot a_2}\right) \cdot \frac{180}{\pi} \quad (19)$$

64 different solutions can be created for axis-2 angle. To define axis angle of axis-4, 5 and 6 ($\theta_4, \theta_5, \theta_6$), Q_{456} need to be calculated.

$$Q_{456} = Q_{123456} \cdot {Q_{123}}^{-1} \;, Q_{456} = [q_{t1}, q_{t2}, q_{t3}, q_{t4}] \quad (20)$$

Axis-4 (θ_4): Below equations needed for defined axis-4' angle.

$$a_3 = a\tan\left(\frac{q_{t2}}{q_{t1}}\right), \; b_3 = a\tan\left(\frac{q_{t4}}{q_{t3}}\right) \quad (21)$$

$$\theta_4 = (a_3 + b_3) \cdot \frac{180}{\pi} \quad (22)$$

128 different solutions can be created for axis-4 angle. *Axis-5 (θ_5):* Below equations needed for defined axis-5' angle.

$$\theta_5 = a\cos\left(\sqrt{{q_{t1}}^2 + {q_{t2}}^2}\right) \cdot \frac{180}{\pi} \quad (23)$$

128 different solutions can be created for axis-5 angle. *Axis-6 (θ_6):* Below equations needed for defined axis-6' angle.

$$\theta_6 = (a_3 - b_3) \cdot \frac{180}{\pi} \quad (24)$$

D. Robotic Specimen Collection Process

A robot kinematic model was created using above kinematic equations to check the application is able to do proses or not. Robotic specimen collection process for Covid-19 has 10 steps to complete all tasks. *Step-1*; Health care worker press button for new job and robot moves to probe loading area from home position. *Step-2*; specimen probe is loaded to the robot by health care worker and loading acknowledgement is confirmed by a safety button. *Step-3*; robot waits patient ready feedback from mouth fixture. *Step-4*; robot moves job-ready position shown in Fig.4(a) and waits a signal from patient's dead-man's switch. *Step-5*; robot moves mouth test point during dead-man's switch pressed shown in Fig. 2(b-c).

Step-6; robot moves pre-position for nose test and waiting ready feedback from patient. *Step-7*; robot moves nose test point during dead-man's switch pressed shown in Fig. 5.

Step-8; robot moves unloading position to unload the specimen probe. *Step-9*; specimen probe is unloaded to the robot by health care worker and unloading acknowledgement is confirmed by a safety button. *Step-10*; robot moves home position and waiting for new job. All tasks has done safely in all steps. Specially, during step-5 and step-7 patient can stop to robot at any time if it create additional force on her/his body (mouth and nose). The safety configuration of the robotic application is based on EN15066 (Robots, robotic devices and Collaborative robots) requirement and also EN-13849 (Safety of machinery- Safety-related parts of control systems). Robot (collaborative robot) itself has force sensor to detect any force changes. However, the force sensors is not more sensitive to detect small force changes in the mouth and nose. This situation needs give the control of the robot movement to the patient during the in operation.

Fig. 4. Specimen collection process for mouth

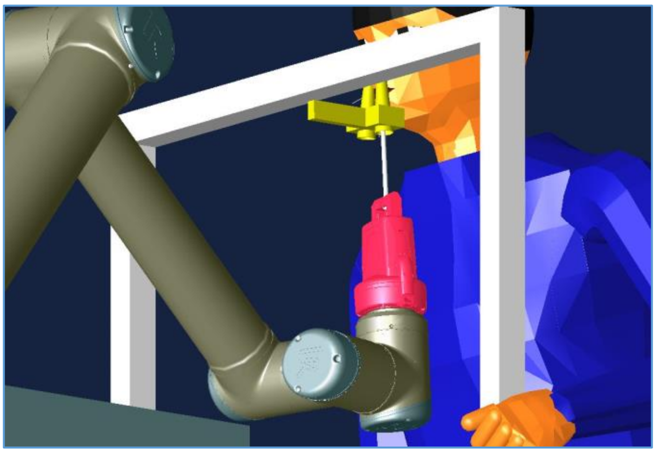

Fig. 5. Specimen collection process for nose

III. CONCLUSION

In this research study, a novel robotic application is developed to achieve fully automatic specimen collection process for new corona virus (COVID-19). All results are;

- Covid-19 specimen collection process with a robotic application has been presented which don't need any health care worker interaction with patient.
- The robotic application has been tested in the plant health care center as a prototype.
- This application is a protection tool for health care workers during Covid-19 pandemic.
- The cycle-time (192 sec) for the robotic process needs to be improved. The Manual process is still %60 faster than robotic application.
- The biggest challenge in this application is patient's mouth and nose physical size changes. Robot movements for the specimen collection in nose and mouth are

arranged just based on the fixed point. This needs to be improved according to size changes.

- Another challenge is force sensor sensitivity. Robot cannot sense any force change during the in specimen collection operations. This challenge is temporary solved with patient oriented robot control function.

This application needs to be improved related with above challenges to make a shelf product. It will create valuable impact and save lives in this pandemic.

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