Summary

Curt 1C

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The recent pandemic had changed the way people live. People are no longer in contact with each other without a mask and are working their jobs at home. Science and technology are very helpful in adapting to these changes in the pandemic. The technology is expected to be of particular great help in the medical field. The COVID-19 is tested by measuring a person's body temperature as the first step. However, people are likely to be reluctant to take their body temperature near them by a doctor or nurse because the disease is so contagious. On the other hand, the doctors and nurses have to wear heavy protective clothing and measure the patient's body temperature, so the level of hardship would be extremely high. The CURT (Coronavirus Unmanned Remote Tester) robot can provide a solution to this situation. The robot can remotely measure the temperature of a person's forehead, just like its name.

The robot had to designed to draw the nominal path of the forehead accurately. So, setting its nominal path and coordinates was very important. In Figure 1, The nominal path was

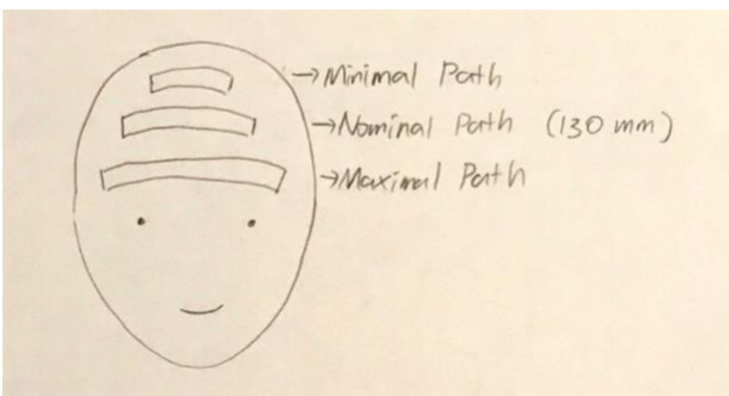


Figure 1: The minimal, nominal, and maximal path of the robot

set up as a 130mm base on the average length of the forehead size of people [1]. The minimal path and the maximal path were determined to be the upper and lower side of the forehead, respectively. This nominal path is based on the average value of a person's forehead, so there is a limit to its use on foreheads of various sizes or shapes. For example, some people with very narrow foreheads will not be able to give accurate figures through the path. In fact, women's forehead sizes tend to be smaller than men's, so the operation of the robot may be limited by gender. This bias in engineering design also can be found in historical cases. According to the techcrunch.com [2], women were seriously injured in a car accident while driving because of a design based on male-biased car crash results. Thus, the robot should be designed to enable the adjustment of the length of the path according to the size of the forehead.

The articulated coordinate system was selected for the robot. With the system, all the movements of the robot could be derived. In Appendix A, a full mathematical derivation was performed, which was from the reference frame to the end manipulator. The derivation of ${}^{R}F_{p}$ was based on approach direction ($\hat{a}$), orientation ($\hat{o}$), and normal direction ($\hat{n}$), which were shown in Figure 2. By taking the inverse matrix of the rotation from the $\hat{a}$ axis ($R_{a\emptyset_a}$), 4x4 matrix

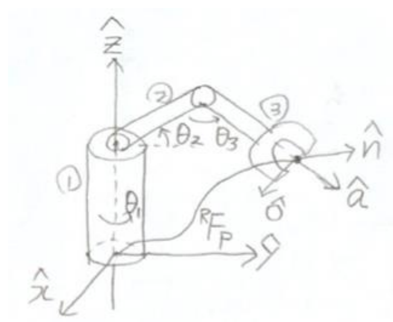


Figure 2: The articulated coordinate system of the robot

multiplication was performed. From the comparison of the two 4x4 matrices, the raw/pitch/yaw angles ($\emptyset_a$, $\emptyset_o$, and $\emptyset_n$) were calculated. The reason I chose the Denavit-Hartenberg representation is that it can describe the position of the end manipulator effectively. With the representation, it is expected that the end manipulator follows the nominal path that I set for in Figure 1. In Figure 3 below, the linkage No. 1 made it possible to rotate 360 degrees, allowing

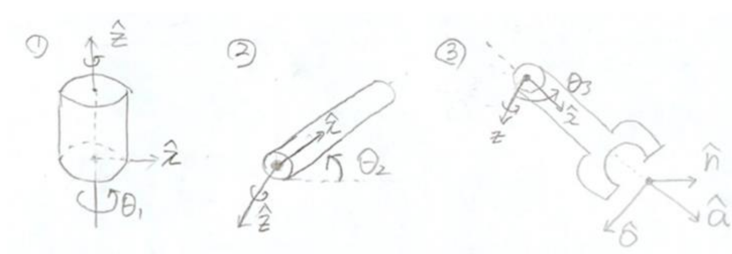


Figure 3: The coordinate choices of the linkages

left and right movements, called “roll”, when measuring forehead temperature. The linkage No. 2 is located at the end of the No. 1 so that it can move up and down, called “pitch”, in order to suit people's different heights. The linkage No. 3, the end manipulator, is connected to the No. 2

to control the proper distance between the robot and the object that measures the forehead temperature, which is called “yaw”.

The stakeholders of the CURT robot consist of medical device manufacturers, medical administration managers, doctors, nurses, patients, and others. First of all, the price seems to be important for medical manufacturers to get interested in the robot. In terms of hardware, the device requires sensors that can recognize a person's forehead, camera lenses, thermometers, linkages that enable various movements, joints, a reference frame, and power sources. In order to reduce the cost of the components, it would be essential for the manufacturers to minimize the distribution process, which is shown in Figure 4.

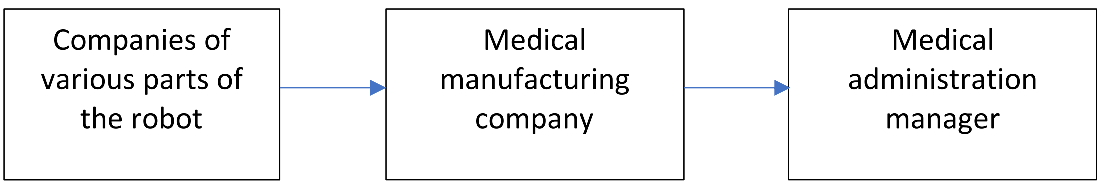


Figure 4: The optimized distribution process

The medical administration manager would prioritize the safety of patients who measure body temperature with the robot. To ensure the safety of the device, the engineers in charge need to run many test drives of the prototype and continue to supplement both the hardware and software. Since the end manipulator is a combination of various products, the engineers would pay more attention to it.

The accuracy of their body temperature is important to increase a doctor’s interest in this device. To do so, the robot must be designed to measure accurately around the forehead at a line that does not degrade the thermometers. In the meantime, the nurse is expected to want the temperature of the patient to be displayed on the patient's health monitor to ease her hassle. To make that possible, a cable must be developed to connect the monitor to the robot and programmed to transmit body temperature inside the robot.

The patients would be very satisfied with their sleep because if the robot measures their body temperature while they are sleeping, their sleep will not be disturbed by the nurses' body temperature measurements. The condition is likely to involve complex programming as the robot must be added with a timer function. A brief sketch of all the stakeholder's requirements is in Figure 5.

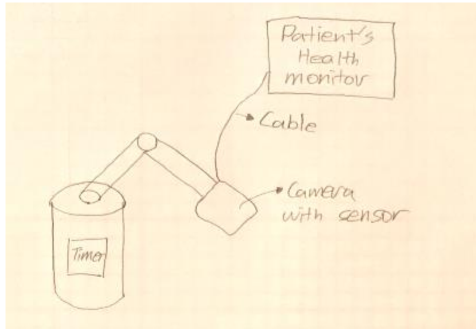


Figure 5: The brief prototype of the robot

In conclusion, the CURT robot was proposed for those suffering from the aftermath of the pandemic. It measured the body temperature by following the nominal path of the forehead. To enable the path, the articulated coordinates system was chosen to derive the movement of the robot in a mathematical manner. The robot was able to move in roll, pitch, and yaw by the mathematical derivation. The five stakeholders were chosen in order to examine what unique things can be added to the robot. By giving reasonable improvement points to the robot, it is expected that the CURT robot can be used in the medical field, effectively.

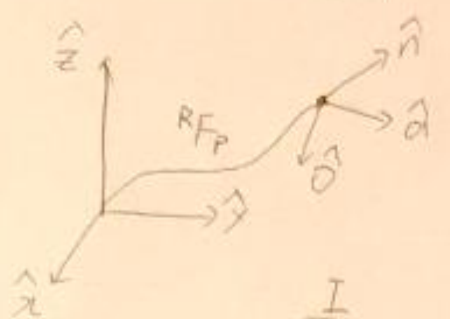
Reference

[1] Dai, H., Pears, N., Smith, W., & Duncan, C. (2019, November 9). Statistical Modeling of Craniofacial Shape and Texture. Retrieved September 16, 2020, from https://link.springer.com/article/10.1007/s11263-019-01260-7

[3] Reiley, C. E. (2016, November 16). When bias in product design means life or death. Retrieved September 16, 2020, from https://techcrunch.com/2016/11/16/when-bias-in-product-design-means-life-or-death/

Appendix A

⟨Math derivation⟩



Roll pitch yaw

$$^{R}F_{p} = R_{a\phi_a} \cdot R_{o\phi_o} \cdot R_{n\phi_n}$$

$$R^{-1}_{a\phi_a} \cdot {}^{R}F_{p} = \overbrace{R^{-1}_{a\phi_a} \cdot R_{a\phi_a}}^{I} \cdot R_{o\phi_o} \cdot R_{n\phi_n} \rightarrow R^{-1}_{a\phi_a}\,{}^{R}F_{p} = R_{o\phi_o} \cdot R_{n\phi_n}$$

$$\rightarrow \begin{bmatrix} C\phi_a & S\phi_a & 0 & 0 \\ -S\phi_a & C\phi_a & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} n_x & o_x & a_x & 0 \\ n_y & o_y & a_y & 0 \\ n_z & o_z & a_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} C\phi_o & 0 & S\phi_o & 0 \\ 0 & 1 & 0 & 0 \\ -S\phi_o & 0 & C\phi_o & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C\phi_n & -S\phi_n & 0 \\ 0 & S\phi_n & C\phi_n & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\rightarrow \begin{bmatrix} n_x C\phi_a + n_y S\phi_a & o_x C\phi_a + o_y S\phi_a & a_x C\phi_a + a_y S\phi_a & 0 \\ n_y C\phi_a - n_x S\phi_a & o_y C\phi_a - o_x S\phi_a & a_y C\phi_a - a_x S\phi_a & 0 \\ n_z & o_z & a_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} C\phi_o & S\phi_o S\phi_n & S\phi_o C\phi_n & 0 \\ 0 & C\phi_n & -S\phi_n & 0 \\ -S\phi_o & C\phi_o S\phi_n & C\phi_o C\phi_n & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

① $n_y \cos\phi_a - n_x \sin\phi_a = 0 \rightarrow \tan\phi_a = \frac{n_y}{n_x} \rightarrow \boxed{\phi_a = \tan^{-1}\left(\frac{n_y}{n_x}\right)}$

② $\begin{cases} n_x C\phi_a + n_y S\phi_a = C\phi_o \\ -n_z = S\phi_o \end{cases} \rightarrow \frac{S\phi_o}{C\phi_o} = \frac{-n_z}{n_x C\phi_a + n_y S\phi_a} = \tan\phi_o$

$\rightarrow \boxed{\phi_o = \tan^{-1}\left(\frac{-n_z}{n_x C\phi_a + n_y S\phi_a}\right)}$

③ $\begin{cases} C\phi_n = o_y C\phi_a - o_x S\phi_a \\ S\phi_n = -[a_y C\phi_a - a_x S\phi_a] \end{cases} \rightarrow \frac{S\phi_n}{C\phi_n} = \frac{a_x S\phi_a - a_y C\phi_a}{o_y C\phi_a - o_x C\phi_a} = \tan\phi_n$

$\boxed{\phi_n = \tan^{-1}\left(\frac{a_x S\phi_a - a_y C\phi_a}{o_y C\phi_a - o_x S\phi_a}\right)}$