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Fault Diagnosis and Force Feedback System of Manipulator for Forest Operation Based on Position Difference

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Abstract:

In this paper, the author mainly researches on the position-position difference based haptic force feedback system of fault diagnosis manipulator for forest operation. Master and slave surgical system is designed to check results in terms of position and velocity in this paper. The results have stability, reliability and repeatability in terms of position and velocity without any force feedback element. The new features are introduced in this paper for producing haptic force feedback element at master handheld device. This architecture is same as in this paper master slave systems, Position-Position Difference control strategy is applied to establish force feedback. The small change in slave manipulator for performing procedures such as needle injecting and ejecting, are discussed. The update control strategy is designed to produce transparent force feedback in terms of position difference for operator/surgeon.

Keywords*: Forest operation; influence factor; position-position defference; haptic force feedback system; fault diagnosis manipulator.*

I. INTRODUCTION

Industrial manipulator is one of the most widely used robots. It is founded on the knowledge from electronic technology, mechanical technology, and automatic control technology. Among industrial manipulators, the mobile manipulator can move and operate simultaneously. Therefore, it is attracting more and more research and application attention in this field. Network control of mobile manipulator is a particular promising field in advanced manufacturing technology. It integrates the robot ology with computer science, communication technology, and control technique. Internet technology further extends the application areas of the mobile manipulator.

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Xiao's [1] paper is about some project, designing a manipulator used for the SG repairing, such as the repairing of the task - plugging pipes. The manipulator has six joints and eccentricity tools set in the end effector. Takeshi's [2] paper has mainly described the work space of the manipulator, the inverse kinematic solution, trace planning, joint control and so on. The collectivity design of control system of the manipulator used for steam generator repairing is presented, including the software system and hardware system of the control system, the function and principle of the system is also described. And then, the task surroundings of the manipulator is analyzed, a collision check method is presented, realizing the attainability space solution of the manipulator under the condition whether the collision is considered or not, then the attainability area of the plugging pipes and the improvement of the work capability occurred after the manipulator inducted the eccentricity tools is analyzed in Gao's paper [3], at last it balances the differentiate of the plugging pipes attainability area before and after the eccentricity tools are inducted. In succession, the kinematic solution is achieved, and then, a research of the questions which have been divided into two parts of eccentricity tools and non-eccentricity tools is made, regardless of the non-redundancy of the manipulator in eccentricity. The solution based on both algebra and geometry is respectively investigated [4]. With a view to redundancy of manipulator in eccentricity tools, the text brings forward the method which is a combination of the algebra method and the optimized method. At the same time, it can ensure the algorithm accuracy and the character of real-time. This text as well studies the collision inverse solution, bringing forward the method of collision avoiding inverse solution based on immunity inherit algorithm. The text puts the speediness into the consideration in order to adapt real-time application. The speed inverse solution of manipulator likewise is studied, based on which the text puts forward the analytic method of the different speed the manipulator has in different work place. Afterwards, the question of the trace planning is studied, binging forward the rank-3 simplified route layout model of this manipulator. Moreover, it opens out the trace planning problem of the manipulator according to both the known-end expected trace condition and the unknown expected trace condition [5-6].

II. POSITION-POSITION DIFFERENCE HAPTIC SYSTEM DESIGN

The Position-Position Difference (PPD) based master slave haptic system is presented in figure 1.The position information is transferred to controller to achieve transparent force feedback on master handheld haptic device during slave interaction with environmental constraint [7]. The block diagram of the proposed PPD system is shown below at figure 1.

In above figure 1 fm is the force, provided by the human on haptic device, pm/Vm is the position and velocity information of the master device. This information is used as an input of the designed controller in first step. The controller produces equivalent voltage signal to the

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slave actuator (Cps) with respect to input position, then slave start moving to desired position. Simultaneously slave feedback sends its current position information (ps) to the controller. The refresh rate of the above cycle is high up to 1.5 KHz to 2.0 KHz, if the slave cannot reach the desired position, then the position difference is generated. This position-position difference is multiplied by force feedback scafing factor(Kfd) and then controller transfers this difference to the master haptic device as a feedback force. The feedback force produces stiffness at master device, which is transparently felt on surgeon's hand.

The position-position difference controller depends on the real position of the master and slave devices [8]. The refresh rate of the controller should be higher as much as possible in terms of slave position update. In proposed surgical system both devices have same mechanical structure and connected with USB 2.0. The refresh rate of the master slave system is about 2 KHz. The real time motion of the slave is maintained by setting the refresh rate high. On the other hand the same difference feedback has to be used for creating force feedback; therefore the refresh rate of the force feedback is lower than the tracking rate. The PPD controller diagram is shown in figure 2.

As mentioned above, the proportional controller is designed to control slave end-effector to track the master haptic device (HD). The proposed tele-robotic control system with PPD force feedback is presented in Figure 2. The force inputs (FsUrg) are given by the surgeon/operator to the master omage.6 HD. The Master HD Changes its position and the position sensors inside the HD update the original position of the hand according to applied force from the operator. Master positions (PMin) are the inputs of the controller. Scaling factor (KS) is used to increase or decrease workspace of the slave side (default value of Ks is 1.00), therefore KS is multiplied with PMin of the HD. The PMKin is the input of difference. The difference is calculated between the reference point (PMKin) and the slave actuator position PSo-t (measured by the slave position sensors). The difference is multiplied by the proportional coefficient of the controller (Kp). Slave actuator input (SAin) is simply the difference of master and slave positions with proportional coefficient of controller (Kp). This difference is multiplied with Kp to obtain the new position of slave actuator PSo-t.

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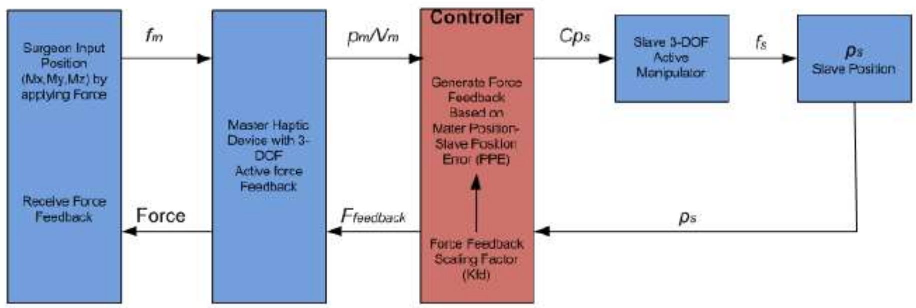

Fig 1: The Basic Model for Position-Position Difference Control

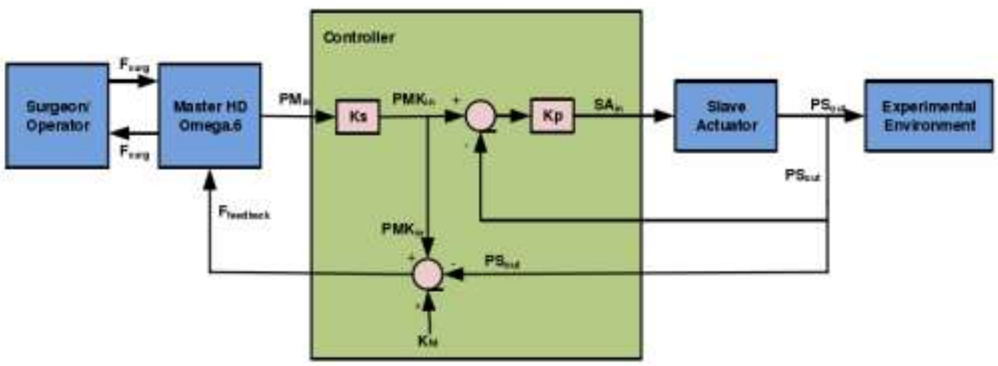

Fig 2: The Process for Position-Position Difference Controller

The refreshing frequency of the system is high to get real time movement without time delay. On the other hand, the same difference has to be used for generating force feedback whenever environmental constraint occurs. The refreshing rate of the force feedback is little lower than the tracking rate of the slave up to 1 KHz. Finally stiffness coefficient (Kfa) is multiplied by the PPD and transfers the result to the haptic device.

III. THE ALGORITHM BASED SOFTWARE DESIGN

After designing the control strategy to PPD based force feedback system, the most problematic task is to employ in real world. Visual C++ 2008 language was the first choice to application software designing. Visual C++ provides Graphical User Interface (GUI) environment for developing application. Microsoft Foundation Class (MFC) from Microsoft

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Corporation and Robotic and Haptic Software development Kit (SDK) from Force and Dimension Corporation are used to design and implement the application software. Application software should be equipped with monitoring and graphical facility; hence, the user can visualized the motion and watch and feel the force feedback effect on the screen and hand respectively. Software enhances the transparency and visual and haptic force feedback of the slave side. The operator/surgeon becomes more confident and comfortable during surgical procedure.

The algorithm can be expressed as following equation (1-2):

$$MTBF = \frac{\sum(downtime - uptime)}{failure\_time} \quad (1)$$

In addition, in engineering, MTBF:

$$MTBF = \theta \quad (2)$$

In probability theory, probability density equations of MTBF in the form of the available *f* (t), namely:

$$MTBF = \int_0^\infty tf(t)dt \quad (3)$$

$f(t)$, refers to that probability density equation of until the next time failure, standard probability density equation:

$$\int_0^\infty f(t)dt = 1 \quad (4)$$

It gives full play use man-machine interface, in which,

$$\alpha^2 = \frac{\rho_0\omega^2}{C_{11}^0},$$

$$\alpha^2 = \frac{\rho_0\omega^2}{C_{66}^0}, \quad \beta_\perp^2 = \frac{\rho_0\omega^2}{C'_{44}},$$

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$$C'_{44} = C^0_{44} + \frac{(e^0_{15})^2}{\eta^0_{11}} \quad (5)$$

Rewrite again Eq. (4) as

$$\begin{aligned}\hat{f}^{\alpha}_{H}(x) &= \frac{1}{\Gamma(1+\alpha)}\int_{-\infty}^{\infty}\frac{f(t)}{(t-x)^{\alpha}}(dt)^{\alpha}\\ &= \frac{1}{\Gamma(1+\alpha)}\int_{-\infty}^{\infty} f(t)g(x-t)(dt)^{\alpha}\\ &= f(x)*g(x),\end{aligned} \quad (6)$$

$$\partial_j(C_{ijkl}\partial_k u_l + e_{kij}\partial_k\varphi) - \rho\ddot{u}_i = 0 \quad (7)$$

$$\partial_j(e_{ijkl}\partial_k u_l - \eta_{kij}\partial_k\varphi) = 0 \quad (8)$$

The linear equation can be expressed into the following simplified forms:

$$L(\nabla,\omega)f(x,\omega) = 0$$

$$L(\nabla,\omega) = T(\nabla) + \omega^2\rho J \quad (9)$$

In which,

$$T(\nabla) = \begin{Vmatrix} T_{ik}(\nabla) & t_i(\nabla) \\ t^T_k(\nabla) & -\tau(\nabla) \end{Vmatrix}, \quad J = \begin{Vmatrix} \delta_{ik} & 0 \\ 0 & 0 \end{Vmatrix},$$

$$f(x,\omega) = \begin{Vmatrix} u_k(x,\omega) \\ \varphi(x,\omega) \end{Vmatrix} \quad (10)$$

Application software for PPD based master slave control is shown in figure 3.

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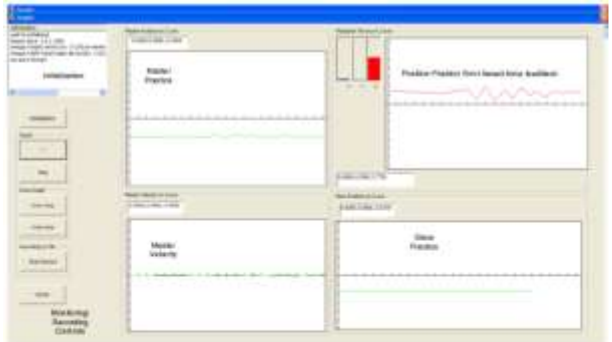

Fig 3: The Software Interface

IV.THE EXPERIMENT ANALYSIS

Experiments have been conducted on different types of structures to ensure the validity of the system at multiple surgical environments.

Experimental result in free Movement: Before starting the experiment on different structure, the first experiment is conducted in free air to calculate the offset error of the system. The experimental results are shown in figure 4. The first graph is about master random positioning in millimeter (mm) with all axes. Different color shows different axis movement in all three graphs, haptic X Y and Z axes movements belong to Blue Red and Green respectively. The maximum difference between master and slave during free air experiment is less the 10.5 mm. These differences are accumulated due to random jerks during change of direction of the master device.

Experimental Result on Pig Tissue: The experimental results are shown in figure 5. The first graph is shown about master positioning in millimeter (mm) with all axes. The upward and downward Z-axis movement is shown in green. The biopsy needle injecting and ejecting experiment is performed. Insertion and extraction on the different places of the pig tissue are repeated four times. The maximum inserting difference in positions is about -2.4mm. The maximum ejecting difference is about 2.6 mm .The little difference happens due to more injecting and variable velocity of the slave. The differences are multiplied by the stiffness factor Kfd and transferred to master device. Pig tissue experiment shows that the injecting difference is little lower than the ejecting due to wire based slave haptic device. The user feels the force feedback on master device during slave injecting and ejecting as shown in figure 5.

Experimental result On Beef Tissue: The experimental results are shown in figure 6. The

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first and second graphs are about master and slave positioning in millimeter (mm) respectively along all axes. The upward and downward Z-axis movement is shown in green. The biopsy needle injecting and ejecting experiment is performed. The maximum injecting difference in positions is about -2.5 mm and it is continuing for four times. The ejecting difference is about 2.5 mm and it also continues four times. The little difference occurs in graph due to more injecting and variable velocity of the slave. The difference multiplied by the stiffness factor Kfa and transfer to master device. Beef tissue experiment shows the injecting and ejecting differences almost equal. The user feels the force feedback on master device during slave injecting and ejecting as shown in figure 6.

Experimental result on Chicken Tissue: The experimental results are shown in figure 7. The first graph is about master positioning in millimeter (mm) with all axes. The upward and downward Z-axis movement is shown in green. The biopsy needle injecting and ejecting experiment is performed seven times. During injecting or ejecting on the different places of tissue, we have got differences in the maximum range of 3.0 to 4.0 mm. The results are not same as in pig and beef tissue. This difference is multiplied by the stiffness factor and transferred to master device. The master device user feels the force feedback on master device during slave injecting and ejecting. This time the ejecting differences are higher due to wire based haptic device.

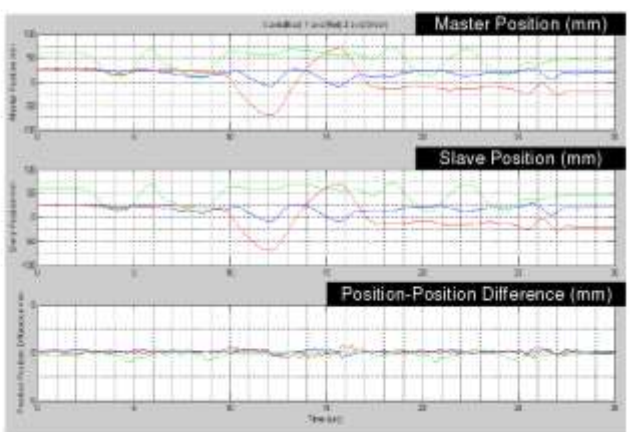

Fig 4: Experimental Results in Free Movement

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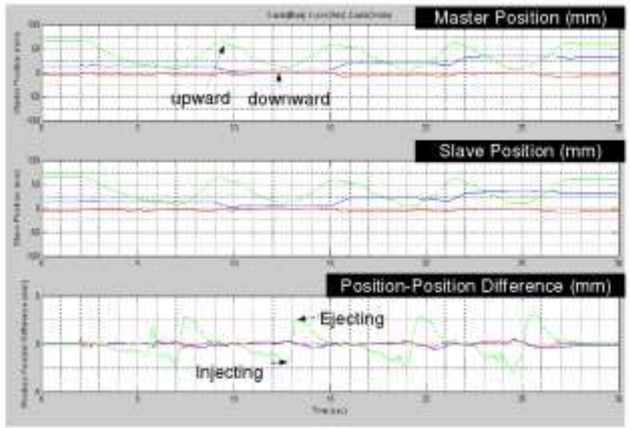

Fig 5: Experimental Results in Pig Tissue

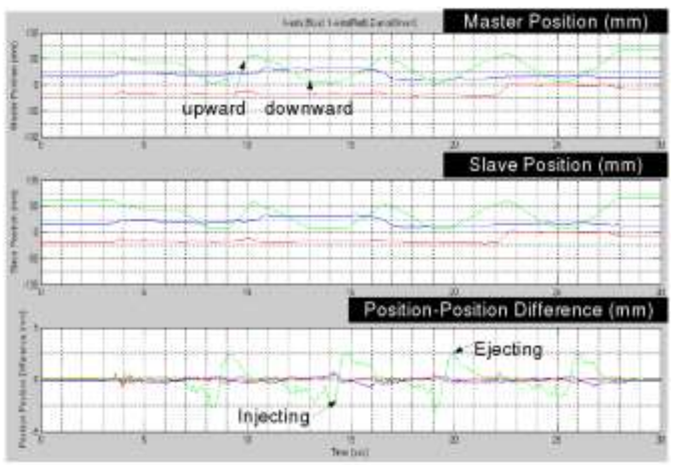

Fig 6: Experimental Results in Beef Tissue

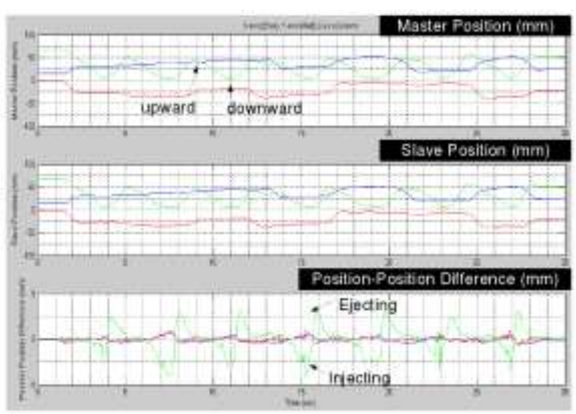

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Fig 7: Experimental Results in Chicken Tissue

V. CONCLUSIONS

In this paper, the author mainly researches on the position-position difference based haptic force feedback system of fault diagnosis manipulator. Master and slave surgical system is designed to check results in terms of position and velocity in this paper. The results have stability, reliability and repeatability in terms of position and velocity without any force feedback element. With a view to redundancy of manipulator in eccentricity tools, the text brings forward the method which is a combination of the algebra method and the optimized method. At the same time, it can ensure the algorithm accuracy and the character of real-time. This text as well studies the collision inverse solution, bringing forward the method of collision avoiding inverse solution based on immunity inherit algorithm. The text puts the speediness into the consideration in order to adapt real-time application. The speed inverse solution of manipulator likewise is studied, based on which the text puts forward the analytic method of the different speed the manipulator has in different work place. Afterwards, the question of the trace planning is studied, binging forward the rank-3 simplified route layout model of this manipulator.

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