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Design and Test of Human Automatic Feeder

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Abstract

At present, medical nursing and disability-assisting mechanical products are mainly wheelchairs, multi-functional beds, toilet supplies, etc., and there are relatively few studies on portable and mobile automatic feeding robots. In order to solve the problem when the elderly and the disabled cannot eat independently, this paper proposed a portable human-use automatic feeding machine, and introduces the working principle of the automatic feeder and the design process of different components. The auxiliary design software of the feeding mechanism of the feeder was developed to obtain a set of better solutions, and then completed the simulation of the virtual prototype and the physical prototype test. The rationality and practicability of the design are verified by comparing the results of virtual prototype simulation and physical prototype test.

Keywords

Feeder; Feeding Mechanism; Non-circular Gear; Design; Test.

1. Introduction

The domestic studies on medical nursing and disability-assisting mechanical products are rich, but mainly are wheelchair, multi-function bed, toilet supplies, but the studies on automatic feeding robots that can be portable, mobile are few. Shandong University of Technology put forward a multi-functional self-feeding and peeing robot, it can make patient moves from the bed to the small car, uses the main navigation to take meals, feed meals, go to the toilet, wash automatically, go to bed automatically, automatically paly in fixed point, and realized the function of human-computer interactive dialogue. However, this feeding robot is bulky, cannot be portable, and is not suitable for personal use at home. Zou Xianjun proposed an automatic food feeding device for patients in orthopedics department, which mainly includes adjustment mechanism and feeding mechanism, this mechanism is complex, the actions that it can realize are relatively simple, and has fewer functions, for example, when the patient needs to switch meals, or when choosing dishes or changing dishes among various dishes, none of these functions can be achieved. Therefore, it has not yet been put into production. The studies on robots mainly include Design Company in the United States and Secom Company in Japan. Design Company developed the feeding robot Obi, the body can hold four dishes, and can control the scooping and feeding instructions through its own two buttons; Secom Company developed the feeding robot My Spoon, disabled can use their mouth, hands or feet to control a joystick to control the robot to realize the instructions of scooping and feeding, and won the Japan Service Robot Award. The above two kinds of robots all complete the feeding action by multi degree-of-freedom manipulator; it is mainly completed by complex electrical control, it is expensive and not suitable for China's national conditions. This paper put forward a new type of portable human feeder, by establishing the mechanism kinematics model, a series of work such as ADAMS three-dimensional virtual prototype simulation and physical prototype test were carried out, the ideal mechanism parameters were determined, and ensure that the mechanism can meet the feeding requirements.

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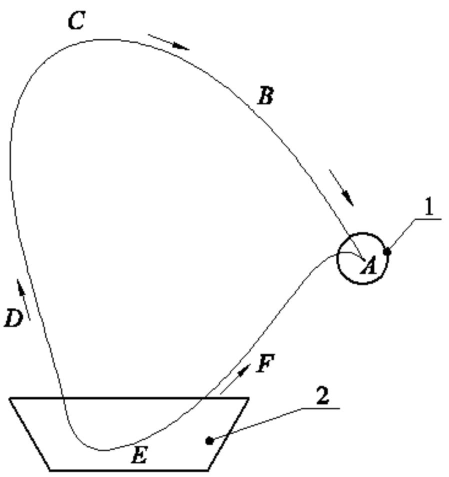
2. Design Requirements of the Feeder

The feeding mechanism (consisting of the transmission gear box and the feeding arm) is the core part of the feeder, the front end of the feeding arm is equipped with an opening and closing spoon, it is the part that directly contact with the food, its end trajectory and posture will directly affect the work effect of taking food and feeding food. According to the trajectory and posture requirements of simulating human hand feeding, the working trajectory shown in Fig.1 is proposed. ABCDEF in the figure is the movement track formed by the spoon tip at the front end of the robotic arm of the food taking mechanism. This trajectory is divided into four parts: (1) trajectory of taking food section DEF, the spoon of the feeding arm inserts into the bowl and slowly picks up food; (2) trajectory of holding food section, the mechanism transports the food to the feeding position; (3) trajectory of feeding food section BA, the push rod moves outwards to drive the opening and closing spoon to open, pours out the food and drop it into the mouth; (4) trajectory of return section BCD, the food taking mechanism returns to the initial position, ready to enter the next feeding action, at this time, the bowl completes a switch. The feeding mechanism needs to complete 4 consecutive actions in one cycle, in order to feed smoothly, the feeding arm should be grasped until the upper left mouth is released after the meal is successfully scooped, and the feeding arm does not touch the bowl at the same time. After the feeding arm is successfully scooped, it should keep grabbing until it is released at the upper left position of mouth, at the same time, the feeding arm does not touch the bowl.



1 Mouth position, 2 bowl position

Fig. 1 Feeding trajectory

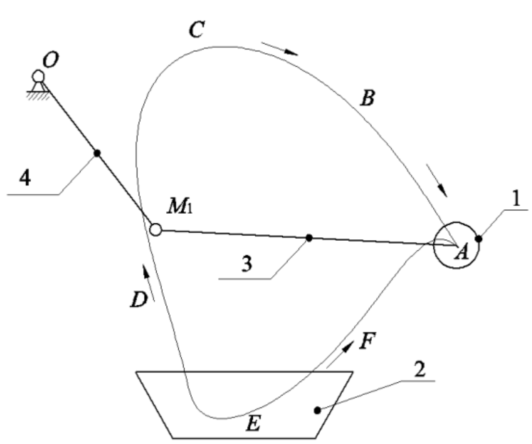


Fig. 2 Schematic diagram of the initial plan of the feeder

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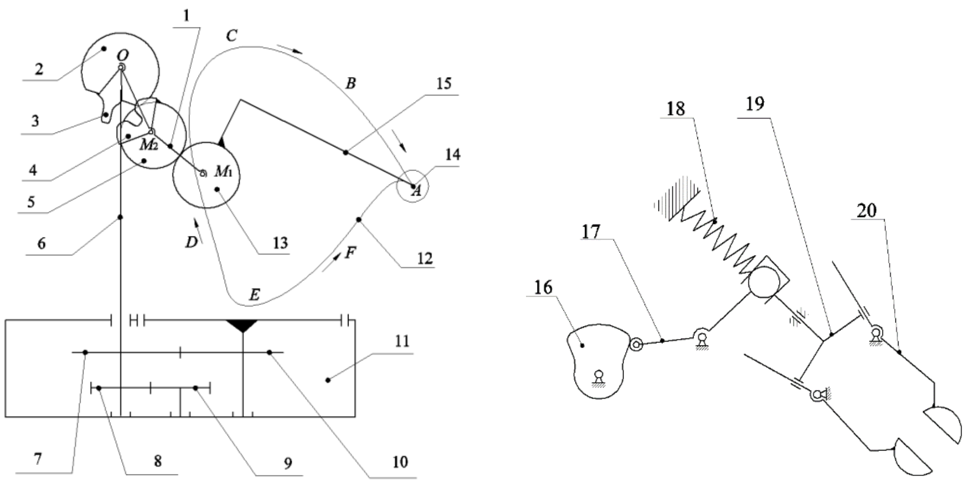
3. Implementation Scheme and Operating Principle of the Feeder

3.1 Implementation scheme

According to the design requirements, the initial plan of the feeder is proposed, as shown in Fig.2. The feeder is composed of rod 1 and rod 2, and two motors drive O_2 and O_1, respectively, and realize the feeding trajectory required by point A at the end. In order to avoid complicated control modules, a solution was conceived. A single motor and drive O_2, the non-uniform rotation of the rod 2 relative to the rod 1 is realized by mechanism which can achieve the non-uniform transmission ratio, in this way, the terminal A realizes the complex feeding trajectory, reduces the degree of freedom to 1, and reduces the number of motor control. Therefore, the scheme driven by the incomplete non-circular gear-non-circular gear combined mechanism is proposed. Fig.3 is a schematic diagram of the feeder and its feeding arm. The feeder is mainly composed of feeding mechanism, base and motor; the feeding mechanism realize feeding trajectory by mainly 1 incomplete gear, 2 non-circular gears, 1 concave gear, 1 cam and 1 feeding arm; the trough plate intermittent mechanism is realized by the groove plate, shifting fork and 2 cylindrical gears to realize the intermittent transmission of different plates; the feeding mechanism and the trough plate intermittent transmission mechanism cooperate to realize the feeding function.



(a) Schematic diagram of automatic feeder (b) Schematic diagram of feeding arm

1 planet carrier, 2 incomplete gears, 3 convex plate, 4 concave plate, 5, middle non-circular gear, 6, sub-transmission shaft, 7 driving plate, 8 driving gear; 9 driven gear, 10, trough plate, 11 base box, 12 feeding trajectory, 13 planet non-circular gear, 14 mouth position, 15 feeding arm, 16 feeding cam, 17 shifting fork, 18 spring, 19 push rod, 20 opening and closing spoon

Fig. 3 Schematic diagram of automatic feeder and its feeding arm mechanism

3.2 Operating principle of feeder

The feeder consists of planet carrier 1, incomplete gear 2, cam 3, concave gear 4, middle non-circular gear 5, sub-transmission shaft 6, driving plate 7, driving gear 8, driven gear 9, trough plate 10, base box, 11, planet non-circular gear 13, and feeding arm 15, the feeding arm is mainly composed of the feeding cam 16, shifting fork 17, spring 18, push rod 19, opening and closing spoon 20. The rotation center of the frame is O, and the rotation centers of middle non-circular gear and planet non-circular gear are M_2 and M_1, respectively. The incomplete gear 2 is fixed with the frame, and the central shaft and the planet carrier are fixed together, when working, the central shaft drives the planet carrier to rotate counterclockwise around point O at a uniform speed, at the same time, the power is distributed to the sub-transmission shaft 6 through the cone gear; the middle non-circular gear 5 revolves counterclockwise around the center of rotation center M2 on the planet carrier as the planet carrier revolves around O. The planet non-circular gear 13 revolves with the planet carrier around O, at the same time, due to the meshing transmission of the middle non-circular gear 5 and the planet non-

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circular gear 13, the planet non-circular gear 13 rotates clockwise around the rotation center M1 on the planet carrier, and the feeding arm stretches spoon tip to form the trajectory of ABCDEF section. EFA is the food-holding phase, AB is the feeding phase, BCD is the return phase, and DFE is the food-taking phase. The feeding cam 16 is fixed to the planet carrier and concentric with the planet shaft, the planet shaft is fixed to the feeding arm shell; the rotation of the planet shaft drives the rotation of the feeding arm shell, in the DFE phase, the shifting fork rotates clockwise under the action of the feeding cam, push rod move forward, taking spoon close; in the AB stage, the shifting fork rotates counterclockwise under the action of return spring, the push rod moves backward, the taking spoon opens, and the feeding and feeding actions are completed.

4. Design of Feeding Mechanism

The feeder completes the feeding action, its core lies in the design of the feeding mechanism, and the feeding mechanism mainly lies in the transmission system design of the irregular gear. The feeding mechanism adopts the combination of incomplete gear-non-circular gear and planetary gear system as the transmission mechanism, the meshing transmission diagram of the incomplete non-circular gear and the middle non-circular gear is shown in Fig.4, the central angle of the toothed part of the incomplete non-circular gear is β, and the central angle of the cam is (2π-β). Suppose that the distance from the rotation center o of the incomplete non-circular gear to the meshing point J is $R1(\varphi 1)$, the distance from meshing point to the rotation center M2 of the middle non-circular gear is $R2(\varphi 2)$, the expression for constructing the incomplete gear pitch curve is:

$$R_1(\phi_1) = \frac{b^2}{a+c\cos(\phi_1+\theta)} \tag{1}$$

In the formula, a, b, and c are the pitch curve coefficients of the incomplete gear, mm; θ is the initial rotation angle of the planet carrier relative to the incomplete gear, rad; φ1 is the angular displacement of the planet carrier relative to the incomplete gear, rad, the variation range of φ1 is 0 to β.

According to the gear meshing relationship, when the middle non-circular gear 1 meshes with the incomplete gear 2, the pitch curve lengths of the meshing parts of the two gears must be equal, namely:

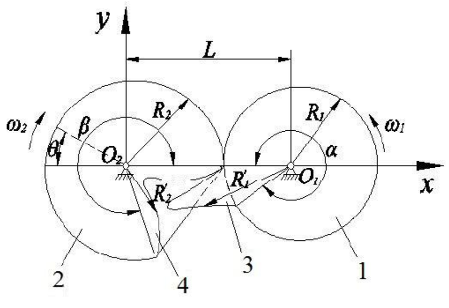
$$R_1(\phi_1)d\phi_1 = R_2(\phi_2)d\phi_2 \tag{2}$$

$$\phi_2 = \int_0^{\phi_1} \frac{b^2}{L_1(a+c\cos(\phi_1+\theta))-b^2} d\phi_1 \tag{3}$$

According to formula (3), we can see that when $\varphi 1=\beta$, $\varphi 2=\alpha$. When the planet carrier rotates clockwise through the β angle, and a, b, c and θ parameters are determined, the center distance L_1 between the incomplete non-circular gear and the middle non-circular gear can be determined via numerical integration. Given:

$$f(\phi_1) = \int_0^{\phi_1} \frac{b^2}{L(a+c\cos(\phi_1+\theta))-b^2} d\phi_1 \tag{4}$$

$\varphi 2=f(\varphi 1)$, so $\varphi 1=f\text{-}1(\varphi 2)$, numerical calculation method is used to establish the relationship between φ1 and φ2.



1 Middle non-circular gear, 2 Incomplete gear, 3. Cam, 4 Concave gear

Fig. 4 Schematic diagram of incomplete non-circular gear transmission mechanism

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$$R_2(\phi_2) = L_1 - R_1(\phi_1), (0 \leq \varphi_2 \leq \alpha) \quad (5)$$

Since the meshing of middle non-circular gear meshes and the planet non-circular gear is full circle, namely 0≦φ2≦2π. The polynomial interpolation method is used to interpolate R2 in the interval [α, 2π], and construct the expression of the radial diameter of the middle non-circular gear *R2*.

$$R_2(\phi_2) = \begin{cases} L - R_1(\phi_1), (0 \leq \phi_2 \leq \alpha) \\ a' + b'\phi_2 + c'{\phi_2}^2, (\alpha \leq \phi_2 \leq 2\pi) \end{cases} \quad (6)$$

In order to ensure that the pitch curve of the middle non-circular gear is smooth and continuous in one cycle, formula (5) meets:

$$\begin{cases} a' = R_2(0) \\ b' + 2 \cdot (2\pi) \cdot c' = \dot{R}_2(2\pi) \\ a' + 2\pi \cdot b' + (2\pi)^2 \cdot c' = R_2(2\pi) \end{cases} \quad (7)$$

From formula (6), the pitch curve coefficients a', b' and c' of the middle non-circular gear can be obtained.

The pitch curve radius *R'1* of the concave plate section, and the center distance *L1* is known, according to the meshing relationship, the pitch curve radius of concave gear plate section *R'2* is obtained by the method of numerical integration. The expression of *R'1* of the radial diameter of the concave gear plate:

$$R'_1(\phi_1) = \begin{cases} A - B\,cos(\phi_1), (\beta \leq \phi_1 \leq \frac{2\pi + \beta}{2}) \\ A + B\,sin(\phi_1 - \frac{2\pi + \beta}{2}), (\frac{2\pi + \beta}{2} \leq \phi_1 \leq 2\pi) \end{cases}$$

$\begin{cases} R'_1(\beta) = R_1(\beta) \\ R'_1(2\pi) = R_1(2\pi) \end{cases}$, the values of coefficients A and B are obtained.

$$R'_1 + R'_2 = L_1$$

$$\int_\beta^{2\pi} R'_1(\phi_1)d\phi_1 = \int_\alpha^{2\pi} R'_2(\phi_2)d\phi_2$$

Obtain the value of *R'2*.

The expression relationship of the first-stage transmission ratio is as follows:

$$i_1(\phi_2(\phi_1)) = \begin{cases} \frac{R_2(\phi_2(\phi_1))}{L - R_2(\phi_2(\phi_1))}, (0 \leq \phi_2 \leq \alpha) \\ \frac{R'_2(\phi_2)}{R'_1(\phi_2)}, (\alpha \leq \phi_2 \leq 2\pi) \end{cases} \quad (8)$$

According to the relationship between the arc length and the corresponding angular displacement when the middle non-circular gear meshes with the planet non-circular gear, the following relational expression can be obtained:

$$R_{21}(\phi_2)d\phi_2 = R_3(\phi_3)d\phi_3 \quad (9)$$

$$\phi_3 = \int_0^{\phi_2} \frac{R_{21}(\phi_2)}{L_2 - R_{21}(\phi_2)} d\phi_2 \quad (10)$$

$$2\pi = \int_0^{2\pi} \frac{R_{21}(\phi_2)}{L_2 - R_{21}(\phi_2)} d\phi_2 \quad (11)$$

$$R_{21}(\phi_2) = R_2(\phi_2(\phi_1) + \pi - \delta)$$

R_{21} is the distance from the center of the middle non-circular gear to the meshing point of the middle non-circular gear and the planet non-circular gear; R_3 is the distance from the rotation center of the planet non-circular gear to the meshing point of the middle non-circular gear and the planet non-circular gear.

The method of numerical integration is used to obtain the center distance L_2, then R_3=L_2-R_{21}.

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The second-stage transmission ratio expression is as follows

$$i_2(\phi_2(\phi_1)) = \frac{R_{21}(\phi_2(\phi_1))}{L_2 - R_{21}(\phi_2(\phi_1))} \tag{12}$$

The expression of total transmission ratio is as follows:

$$i(\phi_2(\phi_1)) = i_1(\phi_2(\phi_1)) \cdot i_2(\phi_2(\phi_1)) \tag{13}$$

In summary, according to the rotation angle relationship of rod 2 relative to rod 1 in Fig. 2, the feeding trajectory can be realized in accordance with the total transmission ratio.

5. Virtual Simulations and Prototype Test of Feeder

5.1 Virtual simulation of feeder

After completing the three-dimensional solid modeling and virtual assembly of the feeding mechanism, the virtual simulation software ADAMS is used to simulate, the operating trajectory of the feeding mechanism is obtained (as shown in Fig.5). Therefore, as shown in Fig.6, the motion trajectory obtained by the virtual simulation can be compared and analyzed with the theoretical work trajectory obtained by the analysis auxiliary software, which initially verify the correctness of the feeding mechanism.

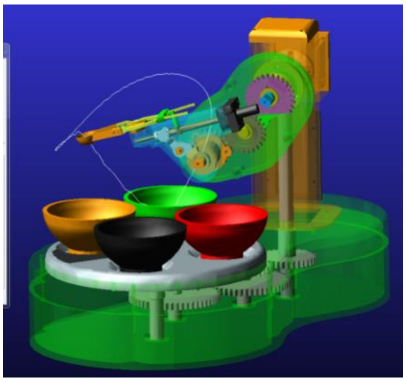
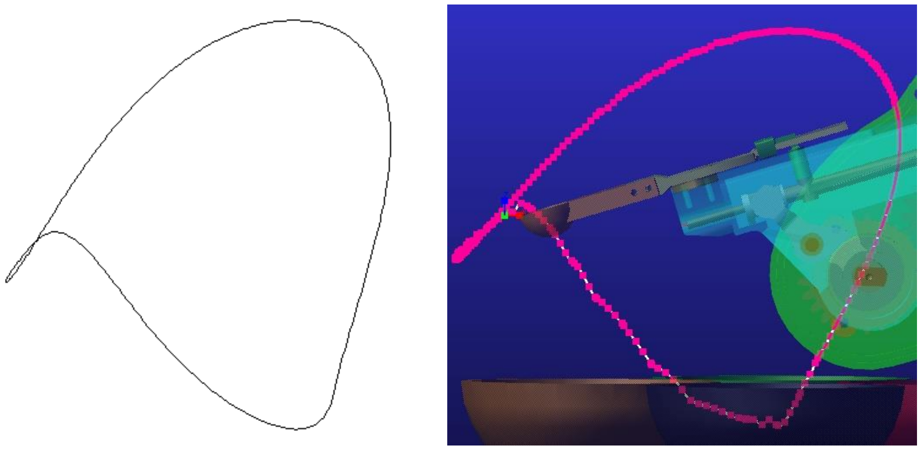


Fig. 5 Simulation test of kinematics



(1) Theoretical design trajectory (2) Virtual simulation trajectory

Fig. 6 Comparison of motion trajectories

5.2 Prototype test

In order to further verify the feasibility of the actual work of the feeder design, the physical prototype of the feeder was processed and manufactured, the human-machine feeding experiment was carried out, and the effect was good.

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Fig. 7 Physical prototype of feeder

6. Conclusion

(1) The current status of existing feeder was analyzed, a new type of human-use automatic feeder was put forward; this automatic feeder can simulate human hands to achieve different food taking and feeding actions, and solve the problem when the elderly and the disabled cannot eat independently.

(2) The virtual prototype simulation was carried out based on Adams software, and this compared the static feeding trajectory obtained by it with the motion trajectory obtained by theoretical calculation, which proves the correctness of the design.

(3) The physical prototype was developed and the man-machine feeding test was carried out, which verified the feasibility of the physical prototype.

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