Research on the Operating Mechanicals of the Helicopter Robot Pilot

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Abstract. The requirements for the quantity and quality of pilots are getting more and more demanding. The helicopter robot pilot was put forward as a new autonomous driving scheme which can achieve fast switch between pilot driving and autonomous driving without modifying helicopters. The overall design of the robot was determined and the actuators of the robot was demonstrated in detail according to the handling characteristics of helicopter manipulation mechanism. Based on the detailed design scheme, the robot pilot was processed and assembled. In order to test the control performance of the robot pilot, the robot was installed in the flight simulator to carry out helicopter flight simulations. The test results illustrated that the robot pilot is able to accomplish basic flight control of helicopter.

1. Introduction

With the development of aircraft technology, the number of aircrafts will be further improved, which puts forward higher requirements for the quantity and quality of pilots. It costs extremely high on training a human pilot, while pilots still take many risks when flying missions in extreme environments such as radiation areas and plateau regions. Furthermore, a large number of newly developed and modified aircraft are in the stage of development and test flight. It takes great risks and may cause great losses for human pilots carrying out these flight tests. Advances in unmanned aerial vehicle (UAV) technology can solve the problem of pilot safety to some extent. However, due to the limited development of artificial intelligence, as well as the low carrying load of UAVs, it can be assumed that manned aircraft will remain the majority in the foreseeable future. Meanwhile, the existing technology which converts manned aircrafts into UAVs is irreversible and costly as well.

Based on the above background, the helicopter robot pilot is proposed as a new automatic driving solution. The helicopter robot driver refers to an autonomous robot system, which can be installed in the helicopter cockpit. The actuators of the robot is connected with the helicopter manipulation mechanism, and the robot drives the helicopter through controlling the terminal movement of each actuator. In the future, the helicopter robot driver can not only carry out flight missions in extreme environments or test flights of new aircraft independently, but also assist the human pilot to complete complicated flight missions as the co-pilot, reducing the number of crew members.

Helicopter robot pilot belongs to the emerging field of aviation and robotics. Relevant research has just started and is being actively carried out. The Korea institute of science and technology (KIST) developed PIBOT in 2014[1][2][3]. The name combines the meanings of "Pilot" and "Robot". PIBOT is shaped like a human, including a head, a torso, arms and legs. The robot's head is equipped with a camera, positioned in the same position as a human eye. The arms and legs can operate actions like a
human. The first generation of PIBOT was a scaled-down version of the commercially available BioLoid enhanced robot suite (BioLoid Premium) and it carried out simulated flight tests of fixed-wing aircraft. The second generation of PIBOT adopted humanoid joint mechanism to control the arms. The kinematic and dynamic characteristics of the manipulator mechanism were studied and a multi-loop PID control system was used for the robot to control the aircraft in the flight simulator. In 2015, Aurora Flight Science in USA developed the “Alias co-pilot” robot. The Alias pilot consists of a robotic arm, a visual head, and a sensor system that monitors the flight instrument data through a camera. The project grew out of DARPA’s early requirements to support autopilot in the crew cabin and was designed to create a closer connection between human pilot and increasingly powerful computers and sensors. The “Alias co-pilot” robot successfully manipulated a small Cessna airplane under the supervision of a human pilot and completed the flight test. In December 2017, the Alias system was installed on UH-1 helicopter and tested for resupply missions.

In this research, a detailed scheme of helicopter robot pilot for typical helicopters was proposed. The position and movement space of manipulation mechanism in the helicopter cabin were measured and simulated. Considering the response speed, control complexity and operation accuracy, the actuators of the helicopter robot pilot were determined. The prototype of the robot pilot was built and installed in the flight simulator to test the actual control performance.

2. Design scheme of the robot pilot

2.1 Helicopter manipulation mechanism
The helicopter robot driver is designed to be mounted in the helicopter cockpit and the actuators should be connected to the helicopter operators. Therefore, it is necessary to accurately measure the position of helicopter manipulation mechanism and establish the movement space of each operator to serve as the design basis for the actuators of helicopter robot pilot.

The helicopter controlled by the robot pilot given in this research is a typical light helicopter SVH4, whose main manipulation mechanisms are a control stick, a total moment throttle and rudders. The position information of operators and seat size in the cabin were measured on the real helicopter and the cockpit environment was established, as shown in Figure 1. The trajectory of the end of the total moment throttle and rudders is in a plane, while the trajectory of the end of the control stick is in a curved surface. Figure 2. shows the motion space at the end of the control stick based on the established cockpit model.

![Figure 1. Helicopter cockpit model](image1)

![Figure 2. Motion space of the control stick](image2)

2.2 Actuator of the control stick
The control stick controls the pitch and roll of the helicopter, and the helicopter needs to adjust its attitude through the control stick at all times during flight. Therefore, the actuator of the control stick needs to have high manoeuvrability and high accuracy. Considering the operation requirement and that the end of the control stick is shifted in three directions, the 3-dof delta parallel robot was adopted as the actuator of the helicopter control stick, as shown in Figure 3.

The delta parallel robot is regarded as a typical 3-dof parallel mechanism in space because of its
compact structure, high efficiency and accurate positioning \cite{4,5}. The 3-dof parallel robot is a spatial mechanism that connects the fixed platform and the moving platform with three identical motion chains at an angle of 120 degrees. In each motion chain, there is a parallelogram closed loop composed of four ball hinges and rod groups. One end of the driving arm is connected to the closed loop, and the other end is connected to the fixed platform by a rotating pair. The three groups of parallelogram mechanisms ensure that the fixed platform and the moving platform are always parallel, eliminating the rotational degrees of freedom of the moving platform and preserving three plane degrees of freedom of space.

**Figure 3.** 3-dof delta parallel robot

2.3 *Actuator of the rudders*

The helicopter rudders change the pull force of the tail rotor through the coordinated control of the variable pitch of the tail rotor to control the helicopter course. The human pilots control rudders mainly by stepping on legs. Therefore, the actuators of the rudders take the form of mechanical legs to achieve human-like operations. The length of the mechanical leg should be adjustable to make it suitable for a variety of helicopters. The end speed of the mechanical leg should have a wide range, which can correct course slowly or change course quickly to fly the helicopter.

The mechanical leg is based on the design concept of imitating human leg to design the executive parts, mainly including thigh, hip joint, knee joint, foot pedal, pushrod, encoder and so on. The overall 3d model of the mechanical legs are shown in figure 4. The mechanical leg uses the servo motor as the power source. In the actual working condition, the operation of the helicopter rudder does not need a particularly fast speed and a large torque. Therefore, the speed of the output rotation of the servo motor at the hip joint was slowed down. Because of the small space in the helicopter cockpit, a relatively compact deceleration device should be chosen. In this research, the harmonic reducer was adopted and the dc motor was selected.

**Figure 4.** Mechanical legs of the robot pilot
Since the two rudders in a helicopter move in tandem, with one side pushing down and the other side pushing up, the robot was designed to adapt to the movement of the rudders. An electromagnetic clutch was installed between the motor and the control thigh to solve this problem. When one side of the mechanical leg drops, the other side controls the break of the clutch to realize the adaptive motion of the rudder. The rotation of the foot pedal was achieved by a push motor fixed to the pushrod. The extension of the pushrod corresponds to the raise of the pedal.

2.4 Actuator of the total moment throttle
The total moment throttle is arranged on the left side of the driver's seat and rotates along the support. When raising the total moment throttle, the automatic tiller rises and increases the total pitch of the rotor blade to increase the tension of the rotor, so as to control the lifting movement of the helicopter. Therefore, the actuator of the total moment throttle was designed as a mechanical arm to realize the lifting function similar to that of the human arm to complete corresponding action.

The total moment throttle only needs to perform a pull up and down action, it has one degree of freedom to operate the arm. The mechanical arm mainly consists of the upper arm, the forearm and the end-effector of the forearm. The upper arm is responsible for the structural support of the manipulator, while the forearm is driven by the dc reduction motor. Through the positive and negative rotation of the motor, the pulling and pressing of the end of the mechanical arm can be obtained.

In order to make the control volume of the mechanical arm have more margin to adapt to different types of helicopters, the upper arm was designed as an angle-adjustable structure. When installing the robot driver, the tilt angle of the upper arm can be adjusted according to the actual position of the total moment throttle. A deceleration motor and a synchronous belt were selected to ensure the stability of the end movement of the mechanical arm and the brushless dc motor was selected.

2.5 Trunk and head structure
The helicopter robot pilot is considered to have image and sensor information acquisition capability to realize remote control function based on visual transmission. For this purpose, the trunk and head of the robot were designed, as shown in figure 5. The trunk of the robot pilot is mainly used to place the power supply, controllers and driver of actuators. Therefore, the trunk part adopted a hollow design and was provided with an external power jack for power inlet and cut-off. At the bottom of the trunk, there was a navigation connector to facilitate the insertion and unplugging of cables. The head of the robot driver is mounted above the trunk and driven by two motors to achieve left-right rotation and up-down pitching. Two sets of cameras were installed inside the head, which can monitor the helicopter indicator panel images and output to the ground station.

The mechanical structure of helicopter robot pilot can be obtained by integrating the above actuators and robot trunk into the SVH4 cockpit, as shown in Figure 5.
3. Manufacture and flight simulation test of the robot pilot

3.1 Manufacture of the helicopter robot pilot

Through the above dynamic analysis, the preliminary dynamic performance and manoeuvring performance of the helicopter robot pilot have been studied. Based on the analysis results, the selection of motors and sensors was determined. The equipment selection, detailed design of the mechanical system and control system of the robot pilot was studied. The parallel robot, mechanical arm and the mechanical legs were processed by aluminium alloy, the robot trunk was processed by 1mm stainless steel, and the robot head was processed by 3D printing. On the basis of the parts processing and the arrangement of electronic components, the assembly and testing of each part were conducted and the lines were connected according to the designed wiring scheme, so as to complete the whole prototype assembly of helicopter robot pilot, as shown in Figure 6. The prototype helicopter robot pilot has compact structure and complete functions. The robot pilot was also installed in the helicopter cockpit to test the control performance of the actuators of the robot, as shown in Figure 7. It has been confirmed that the actuators of the robot pilot is well connected with the helicopter manipulation mechanism and can complete quick and sensitive motion control.

![Figure 6. Manufacture of the helicopter robot pilot and the installing test](image)

3.2 Flight simulation test of the helicopter robot pilot

In order to verify the control performance of the robot pilot, the robot pilot was installed in the flight simulator to conduct flight simulation test. The flight simulator adopted the X-plane flight simulation platform. The robot pilot fly the helicopter through the joystick that connected the computer and output signals to X-plane. The joysticks were fixed with the actuator terminals of the robot pilot, as shown in Figure 7.

The flight test mainly simulates the helicopter hovering, rolling, yawing and landing performance. During the test, the mechanical arm was executed through the upper control software to perform the pull up action on the total moment throttle and then it can be observed that the helicopter slowly raised in the computer screen. When the helicopter climbed to a certain height, the helicopter pitching and rolling action can be realized through controlling the joystick forward, backward, left and right through the
parallel robot. At the same time, the helicopter can also yaw by controlling the mechanical leg. After
the simulation of all these actions, the total moment throttle was forced to pull down gradually and the
helicopter slowly landed to the ground, so as to complete the flight simulation test.

![Figure 7. Flight simulation of the helicopter robot pilot](image)

4. Conclusions
In this research, the helicopter robot pilot was put forward as a brand new autonomous driving scheme
based on the thought of modularity, which can achieve fast switch between the pilot driving and
autonomous driving without modifying the helicopter. The measurement of the helicopter cockpit was
used to establish the working space for the helicopter robot pilot. Then, the overall scheme of the
helicopter robot pilot was discussed and designed. The actuators of the robot to control the helicopter
manipulation mechanism were investigated in detail and the mechanical structure and sensor placement
of various parts were determined.

Based on the selection of robot equipment, the detailed design of the mechanical system and the
control system, the prototype of the robot pilot was processed. Accordingly, a flight simulation platform
was built to carry out flight simulations using the robot pilot. It was demonstrated that the robot pilot is
able to fly the helicopter in the flight simulator and complete taking off and landing, hovering, rolling
and yawing actions.

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