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CONTROL OF UNDER ACTUATED - VTOL SYSTEM USING GLOVE CONTROLLER

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ABSTRACT

In today's world, the study and applications of Vertical Take-Off and Landing (VTOL) capable Unmanned Aerial Vehicles (UAVs) have increased vastly. A wide variety of UAVs are currently being employed in both civilian and military sectors. In remote control (RC) technology, the VTOL system is also implemented in RC aircrafts and helicopters. In this paper, our focus will be on the Tilt-rotor model. The Tilt-rotor has a rotor on each side of its airframe, where it can tilt to provide both lift and forward thrust to the rotor-craft. The Tilt-rotor craft is controlled via glove controller wired by human. The glove controller drives the rotor of the aircraft model based on the hand motion, allowing the glove wearer to manipulate the VTOL system of the aircraft including pitch, yaw and row movement of the aircraft.

Keywords: UAVs, glove controller, unmanned system.

INTRODUCTION

This paper is about implementation of smart glove controller into Vertical Take-Off and Landing (VTOL) system using an existing laboratory remote-control (RC) aircraft model. VTOL aircraft capable to take-off with the agility of a helicopter while retaining the efficiency and speed of an airplane during conventional flight. By using the smart glove controller, the speed of rotor for VTOL can be adjusted to different level, providing a more flexible control to the aircraft model and thus improve the stability of the model in term of step response. It also adds a human touch to control interface compare to the joystick controller. Flexible sensor on the smart glove controller will detect the finger motion of the wearer. The detected analog signal is sent to Arduino microcontroller board to be converted to digital data. The Zigbee wireless module is introduced in the project to provide a wireless signal transmission from controller to the remote-control (RC) VTOL model.

There are some limitations based on the current control system techniques on the tilt-rotor system as they are hard to achieve stability and less flexibility. Therefore in this paper, the smart glove controller concept will be implemented similarly to the RC tilt rotor aircraft model to see if it provides more stability to the aircraft.

Figure-1. Tilt-rotor system as test bed.

The objectives of this project are summarized as: (i) To develop a smart glove controller to remote control VTOL system via wireless control mechanism and (ii)To analyze and compare the stability of VTOL system using smart glove controller with conventional handheld controller.

MOTIVATION

According to [1], VTOL is defined as a flight system which an aircraft can hover, take off, and land vertically. This classification includes fixed-wing aircraft as well as helicopters and other aircraft with powered rotors, such as cyclocopters and tilt rotors. Some VTOL aircraft can operate in other modes as well, such as CTOL (conventional take-off and landing), STOL (short take-off and landing), and/or STOVL (short take-off and vertical landing). Others, such as some helicopters, can only operate by VTOL, due to the aircraft lacking landing gear that can handle horizontal motion. VTOL is a subset of V/STOL (vertical and/or short take-off and landing). Besides the ubiquitous helicopter, there are currently two types of VTOL aircraft in military service: craft using a tilt rotor, such as the Bell Boeing V-22 Osprey and Bell XV-15. Generally speaking, VTOL aircraft capable of V/STOL use it wherever possible, since it typically significantly increases takeoff weight, range or payload compared to pure VTOL.

The reason that tilt-rotor model was chosen in this project isn't because of its distinctive appearance. In [2] it was stated that one of the superiority of tilt-rotor compared to other multi-rotor helicopters is that it requires only two motors, allowing a reduction in weight, volume and energy consumption. Besides that, it offers faster reaction than a fixed-wing airplane with the aid of two rotors.

In [3] the tilt-rotor based mechanism which providing roll, yaw and pitch moment was briefly described. The controller was then designed based on back-stepping method. Due to the complexity of the non-linear model, assumptions and considerations on tilt-angle were made in the controller design. Although the stabilization of the tilt-rotor is achieved, its control law design involves nested saturations. Another similar example of controller design based on this method was stated in [2] whereby non-linear control law was also used but much simpler to use and did not require linearization, thus assumptions as in [3] can be excluded.

One of the methods to control the tilt rotor was stated in [4] where adaptive model inversion flight control was used. Although the combination of adaptive control and Neural Network (NN) proved to be success in gaining stability, this control augmentation involves complex neural network architecture which took time to compute.

In [5] by Mondal *et al.* the Second Order Sliding Mode (SOSM) Controller is proposed to the linearized model of VTOL aircraft. Assumptions were made during controller design part due to uncertainties in practical control systems.

Another case study proposed linearized model of VTOL aircraft in [6] used input-output feedback linearization method to transfer a nonlinear system into a linear one. As a result, linear control methods can be used to design controller to be implemented to the linearized system. There are H: loop shaping design, state feedback with integrator method and also PD controller method. Their step responses were compared among each other by considering with and without actuator dynamics.

In [7], a robust control method which combines sliding mode control with the fuzzy control was presented. The simulation result was proved success to eliminate chattering problem completely. However, this control method was only applicable when rotation of the nacelles was the same and fuzzy rules were determined.

In the tutorial notes [8] by Dr. Cazzolato describes the mathematical model and state equation for the 3 degree of freedom hover system.

Although there are few examples where there several types of controller are made for VTOL system, none of them try to use glove controller for VTOL system before. Furthermore, the stability of previous research on VTOL system is not very good and still need to be improved.

The earliest utilization of glove controller can be traced back to [9] in year 1987 where Z-glove and DataGlove were introduced for hand-machine interface. Both contain flex sensors which used to measure finger bending and they are proved to provide a real time and more flexible control compared to controller such as touch pads and mice.

In [10] the smart glove controller was used to control an artificial hand gripper. During the research, they have been study the effect of finger bending activity to the resistance of the flex sensor on smart glove controller.

Paper in [11] showed example where hexapod is controlled using smart glove controller. According to [11] by Akshay D R and Dr. K Uma Rao, they control the hexapod using microcontroller as regulator and Analog-to-Digital Converter for the analog sensors on glove. The signal is then sent to the transmitter. The transmitter sends signal to receiver. At receiver, the values are read and decoded before fed to microcontroller. Finally the microcontroller processes the information and energizes the actuator. RF module is used to provide wireless communication for the glove controller. Nevertheless, the sensor used which is made up of combination of voltage divider circuit and IR transmitter and receiver, causing a lot of wire connections needed which contribute to messy and bulky glove controller. In [12] by Youngin Choi, the hardware of the compact data glove system consists of flex sensors, 8-bit microcontroller unit and Zigbee wireless module.

METHODOLOGY

The Tilt-rotor system control using glove controller has utilized a few electronic components such as flex sensor, Arduino UNO board and Zigbee radio wireless module. The flex sensor has a typical electrical resistance variation when flexed or bent. When flex sensor is bend outward, resistance value increased significantly as the angle of flex sensor is bend further. In this project, the flex sensors are attached on back of the smart glove. The sensor is connected to an Arduino UNO board, an open source microcontroller board based on ATmega328 for analog signal detection. The reason for choosing Arduino board is that it is inexpensive and it provides USB interface which make serial communication extremely easy.

In order to read the flex sensor, its variable resistance is converted to a variable voltage and amplified with an op-amp. Then, the analog signal is transmitted to the 10 bits A/D converter in the microcontroller side for data processing. Then, the converted signal will be transmitted to the Zigbee transmitter which later will send signal wirelessly to the Zigbee receiver mounted on the model of aircraft. Lastly, the data will be sent to the rotor as electrical signal to rotate the propeller and create up thrust to lift the model. Figure-2 shows the block diagram for this system.

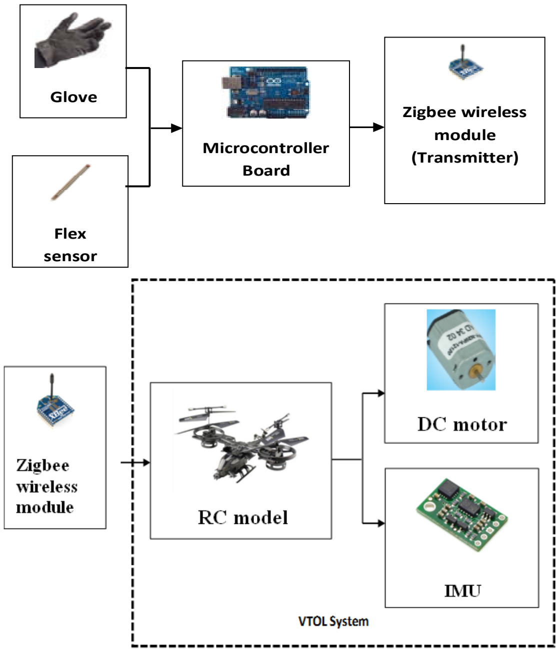


Figure-2. System block diagram.

Zigbee radio wireless module is a radio hardware which uses a microchip to provide simple, standards-based point-to-point communications. It offers several kinds of standards-based ZigBee mesh networking, enable creating of robust sensor networks.

EXPERIMENTAL SETUP

Experimental setup to control stability of the tilt-rotor system has been done. The Inertial Measurement Unit (IMU) is connected and attached to the rotor system. Then, the flex sensor is connected to circuitry system which then sends the signal through zigbee module to the rotor system is setup. After that the zigbee signal receiver that is connected to electronic circuit is connected. Figure 3 shows the Glove Controller setup while Figure 4 shows the tilt-rotor experiment setup to test stability with IMU attached.

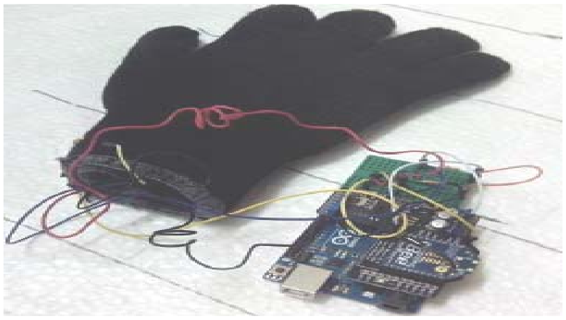
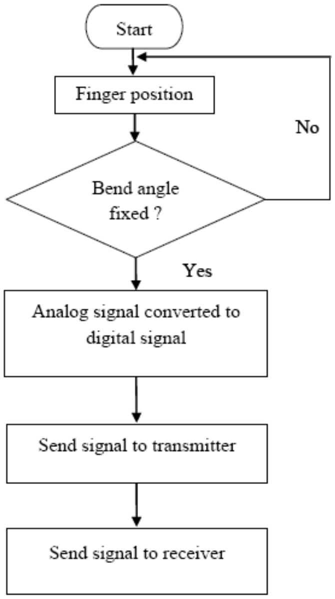


Figure-3. Glove controller setup.

Figure-4. Tilt-rotor experiment setup.

The process flowchart for the system to operate is shown in Figure 5. The process flowchart for host and node are designed based on the sensors to show the control mechanism of the RC model using smart glove controller.

In the experiment to determine the helicopter's stability, only 2 gyroscopic data set were obtained from the IMU. The two data sets were angular rate at x-axis and angular rate at y-axis of the helicopter model. One corresponds to the helicopter model's roll movement while the other corresponds to the helicopter's yaw movement. Less fluctuation in the waves generated in serial chart indicates more stability offered by the controller. The experiment is conducted two times, one for the conventional hand-held controller before the smart glove is implemented while the other is conducted after implementation. Two sets of serial results will be shown in Serial Chart. The results are then compared to see which offers more stability.



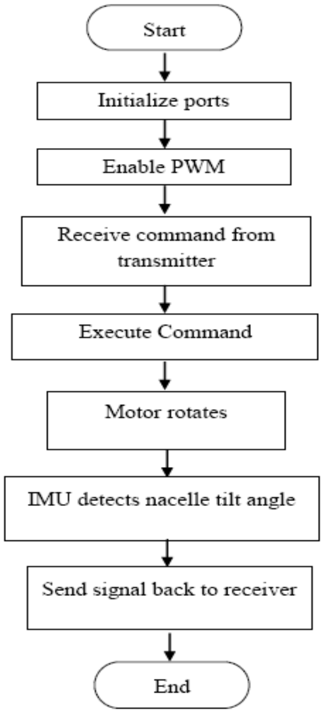


Figure-5. Process flowchart for tilt-rotor system using glove controller.

RESULT

The results for the flex sensor that is used inside glove controller are initially discovered. Figure 6 shows a graph of resistance versus bend angle measured via multimeter while Figure 7 shows graph comparison of resistance values from multimeter test and values from serial chart of controller.

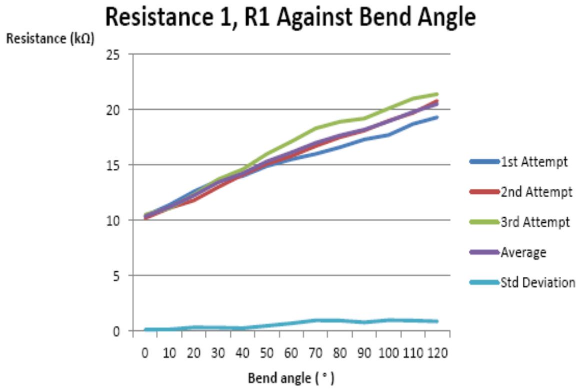


Figure-6. Graph of resistance versus bend angle measured via multimeter.

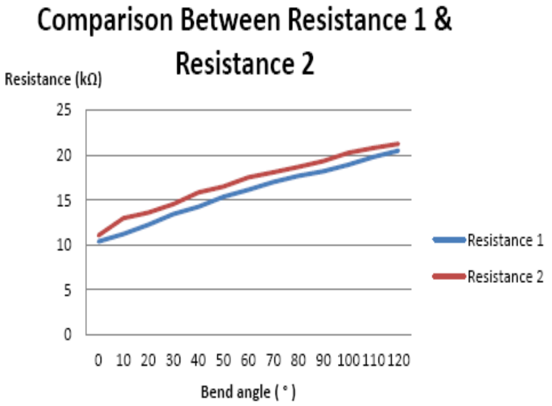


Figure-7. Graph comparison of resistance values from multimeter test and values from serial chart of controller.

In the Figure-6, three sets of resistance value are compared. The resistance value for every attempt increased gradually when the sensor is bended outwards. The difference among each attempt is due to human error and the ±30% resistance tolerance of the flex sensor as the mentioned in datasheet. The average resistance obtained showed a linear pattern line and is close to all three attempts. Low standard deviations in R1 further indicates that the resistance value for all three attempts are very close to the average.

In Figure-7, the resistance values show no much difference. The result from R2 is slightly lower than R2 because of meter inaccuracies and loading effect of the meter. By comparing the resistance test result and the specification of the sensor, the difference is insignificant when sensor was not bended since the inflexed resistance of the sensor is approximately 10 kΩ. However, the resistance value is a little biased from the specification of the sensor in datasheet when the sensor is bended 90 outwards. The bend resistance is supposed to give 14 kΩ but the multimeter read 18.2 kΩ.

Stability Test Result and Analysis

After the preliminary results have been identified from the flex sensor movement, the results from IMU experiment are taken. The Figure 8- Figure 9 are taken before the implementation of smart glove where they are taken from the joystick controller. From the graph shown, the xGyro and yGyro contain noises. It is because of the integration over time, the measurement has the tendency to drift, not returning to zero when the system went back to its original position. The IMU's gyroscope data is reliable only on the short term, as it starts to drift on the long term.

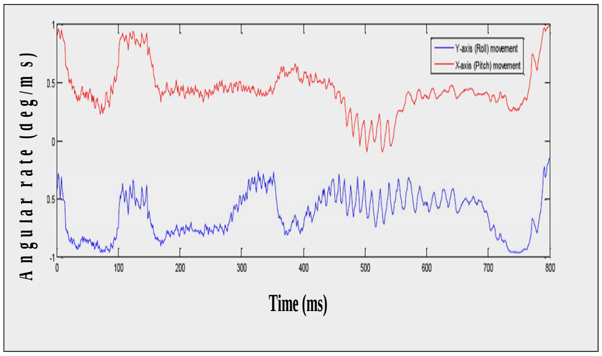


Figure-8. Stability result using handheld joystick controller before noise filteration.

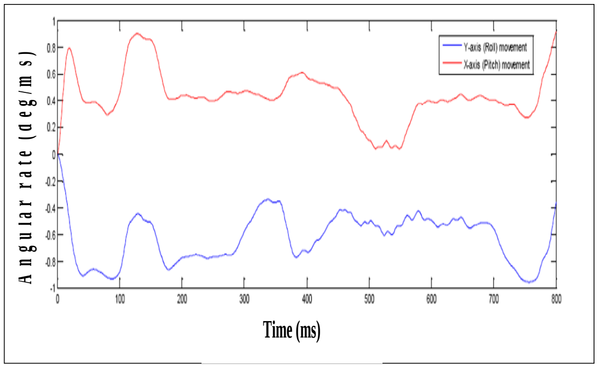


Figure-10. Stability result using handheld joystick controller after noise filtration.

The same method is used when obtaining data result for smart glove controller implementation on VTOL.

Figure-10 and Figure-11 show the stability result using Glove Controller before noise filtration and after noise filtration. By comparing Figure-10 and Figure-11, the x-axis angular rate after the implementation seem to varies in a small range within 0 deg/s to 0.4 deg/s after achieving a steady state for a certain time compared to the x-axis angular rate before the implementation which ranges from 0.2 deg/s to 0.8 deg/s . This indicates that less tilting occurred or less roll motion for the aircraft model when it is meant to take-off vertically after smart glove controller system applied. Apart from that, the overall pitch motion's angular rate also reduced significantly after the implementation of smart glove controller. The pitch motion happened on the aircraft was mainly due to the weight of the circuit board and IMU mounted on the aircraft which result in slightly unbalance during the vertical take-off motion. Nevertheless, it doesn't impact much on the experiment and the smart glove controller proved to increase the stability along the Y-axis of the model as well.

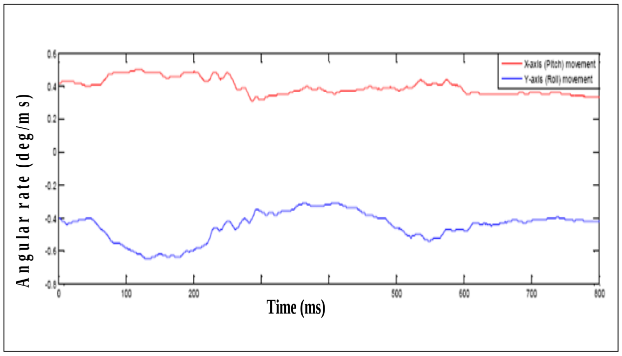


Figure-9. Stability result using glove controller before noise filteration.

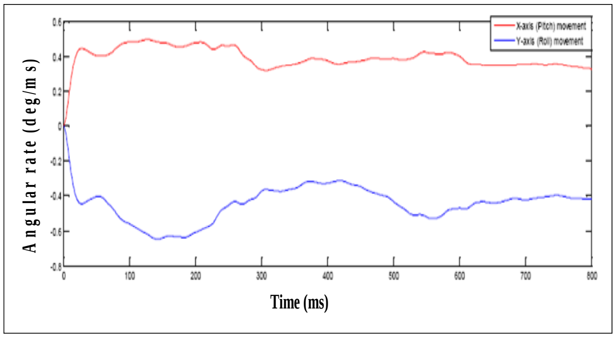


Figure-11. Stability result using glove controller after noise filtration.

CONCLUSIONS

In conclusion, the results from the flex sensor are acceptable and the Arduino Target functional test shows positive result. The development and implementation of glove controller for vertical take-off and landing (VTOL) is proved to offer more stability compared to conventional handheld controller. This success would lead to great potential of development and implementation of smart glove controller in various kind of field not only VTOL and remote control kit but in medical, search and rescue and military as well in the future. Further study for glove controller is recommended in future work and it is suggested to be connected to Data Acquisition Card (DAQ) since it has great potential to become more advance with latest state of the art technology and control system.

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