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On-line adaptive controller system used on small UAV

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Abstract

Since Small Unmanned Helicopter flight attitude control process has strong time- varying characteristics, and there are random disturbances, the conventional control methods with unchanged parameters are often unworkable. An on-line adaptive ADRC control system is designed in this paper. An on-line adaptive ADRC system implements a simultaneous on-line tuning of ADRC rules. The flight experiment showed that the proposed adaptive ADRC system provides quicker response, smaller overshoot, higher precision, robustness and adaptive ability. It satisfies the needs of autonomous flight

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Keywords: small UAV; on-line adaptive; ADRC

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_1$</td>
<td>the control goal</td>
</tr>
<tr>
<td>$\nu_2$</td>
<td>the differential of the control goal</td>
</tr>
<tr>
<td>$z_1$</td>
<td>the state variable</td>
</tr>
<tr>
<td>$z_2$</td>
<td>the differential of the state variable</td>
</tr>
<tr>
<td>$z_3$</td>
<td>the interference variable</td>
</tr>
<tr>
<td>$e_1$</td>
<td>the error variable</td>
</tr>
<tr>
<td>$e_2$</td>
<td>the differential of the error variable</td>
</tr>
<tr>
<td>$\mu_0$</td>
<td>the initial control variable</td>
</tr>
<tr>
<td>$\mu$</td>
<td>the control variable</td>
</tr>
</tbody>
</table>

1. Introduction

Helicopters would be very suited for inspections and surveillance tasks, etc., due to their 3-dimensional maneuverability. Recent dramatic progress of electrics and computer technologies is contributing to development of an autonomous operating system for small unmanned helicopters (SUH). Once a small unmanned helicopter is fully realized, it is possible to operate the helicopter outside an operator’s direct line of sight, facilitating helicopter transport and operation. Such a compact
helicopter can be stored in limited space, and operation not involving difficult manual flight operation reduces development, purchase, and operation costs while ensuring superior safety and reliability.

Therefore, on the basis of the analysis of the two new aircraft, tilt-rotor aircraft and ducted fan aircraft, the research team combines the advantages of the two and proposes a new type of SUH: dual ducted tilting super-mini UAV system (Fig.1). The aircraft changes the lift force of the aircraft by tilting the system to change attitude for the purpose of further navigation flight. New unconventional aerial vehicles provide novel vehicle platforms that allow for a wide operating envelope that have the potential to be especially useful in search and rescue operations.

Fig.1. New kind of small UAV system.

Active Disturbance Rejection Controller (ADRC) is evolved from the Nonlinear PID controller. It inherits the PID controller’s simplicity, easily to implement, and good robustness advantages[1], and overcomes the PID advantages of having no unreasonable methods for error extracting, no approach to extract error differential, and hard to find an ideal coefficient combination of a system. It takes the system’s internal disturbance and external disturbance as total disturbance, and then compensate for this total disturbance[2].

At present, the ADRC is widely used in many robotic systems. ADRC algorithm is complex, and has many parameters to be tuned. Parameters appropriate or not directly related to the ADRC control effect of actual object. ADRC common parameter tuning method is use computer-aided software or self software to estimate and select the parameters, which makes the system performance can’t gain an optimum performance.

In this paper, a new Adaptive ADRC controller is designed, which implement an Adaptive control module to adjust the ADRC control parameters. Finally, use the vector system of the aircraft, underwater robots, and other verification to prove the feasibility of the method, and get good results.

2. Methodology for adaptive ADRC controller

2.1. Active disturbance rejection controller (ADRC)

The block diagram of ADRC is shown in Fig.2. ADRC Controller Complete algorithm is follows[3]. Using $v_0$ as input, Arrangement Transition Process

$$
\begin{cases}
    e = v_1 - v_2 \\
    fh = fhan(e, v_2, r, h) \\
    v_1 = v_1 + hv_2 \\
    v_2 = v_2 + fh
\end{cases}
$$

(1)
Fig. 2. Block diagram of ADRC.

1. Using the input and output of a system to track and estimate the system state and perturbation.

\[
\begin{align*}
\mathbf{e} &= \mathbf{z}_1 - \mathbf{y}, \quad \mathbf{fe} = \text{fal}(\mathbf{e}, 0.5, \delta), \quad \mathbf{fe}_1 = \text{fal}(\mathbf{e}, 0.25, \delta) \\
\mathbf{z}_1 &= \mathbf{z}_1 + h(\mathbf{z}_2 - \beta_0 \mathbf{e}) \\
\mathbf{z}_2 &= \mathbf{z}_2 + h(\mathbf{z}_1 - \beta_0 \mathbf{fe} + \beta_0 \mathbf{u}) \\
\mathbf{z}_3 &= \mathbf{z}_3 + h(-\beta_0 \mathbf{fe}_1)
\end{align*}
\]

where \(\beta_0, \beta_1, \beta_3\) is a set of parameters.

2. Law of state error feedback

\[
\begin{align*}
\mathbf{e}_1 &= \mathbf{v}_1 - \mathbf{z}_1, \quad \mathbf{e}_2 = \mathbf{v}_2 - \mathbf{z}_2 \\
\mathbf{u}_0 &= k(\mathbf{e}_1, \mathbf{e}_2, \mathbf{p})
\end{align*}
\]

where \(\mathbf{p}\) is a set of parameters.

3. Disturbance compensation process

\[
\mathbf{u} = \mathbf{u}_0 - \frac{\mathbf{z}_3(t)}{\beta_0}
\]

2.2. Arrangement for the transition process based on Adaptive algorithm

The function \(\text{fhan}(\mathbf{x}_1, \mathbf{x}_2, r, h)\) in Arrangement Transition Process is a second-order discrete system’s optimal Integrated control function:

\[
\begin{align*}
\mathbf{x}_1(k+1) &= \mathbf{x}_1(k) + h\mathbf{x}_2(k) \\
\mathbf{x}_2(k+1) &= \mathbf{x}_2(k) + hu, \quad |u| \leq r
\end{align*}
\]

In Arrangement Transition Process, it is hard to accurately maintain the output speed at zero and the output may have high-frequency vibration. The longer the step, the greater the vibratory amplitude will be.

In order to weaken the high-frequency vibratory signal, we can choose a shorter step. But, at the same time, a shorter step will bring a slower corresponding rate. In an actual system, inputs \(\mathbf{u}_0\) and outputs \(\mathbf{u}_0\) can be measured. So in this page
we use a subsidiary self-immunity system—On-line Adaptive Controller 1 (shown in Fig.3) to adjust the arrangements of
the transition process[4].

![Fig.3. Block diagram of Adaptive ADRC.](image)

When the error between actual output and desired output is large, the on-line adaptive controller makes the step to be
longer. So the outputs can quickly reach to the inputs. When the error between actual output and desired output is small, the
focus is to eliminate the output's high frequency vibration. So the On-line Adaptive Controller 1 makes the step shorter, and
the outputs will be with weaker vibration. The input of the On-line Adaptive Controller 1 is the error and the error changing
rate between the input and output of the control object.

However, it is apparently irrationality to add the modificatory data to all ADRC rules. The reason is that it is not all
ADRC rules to answer for the output error of the current state. To this question, this paper puts forward the following
arithmetic:

\[
\delta^{0} : \nabla h^{0} = \delta(v_{01}, v_{02}, v_{03}, \ldots, v_{0n})u_0
\]

where $\nabla h^{0} : f_{\text{han}}(x_1, x_2, r, h)$ is the modificatory data of step $h^{0}$; $u_0$ is the output of the On-line Adaptive Controller
1; $\delta(v_{01}, v_{02}, v_{03}, \ldots, v_{0n})$ is the responsibility coefficient.

This paper puts forward the responsibility coefficient $\delta$:

\[
\delta(v_{01}, v_{02}, v_{03}, \ldots, v_{0n}) = C \hat{\delta}^{0} = C \frac{\delta^{0} (\prod_{n=1}^{r} \delta_{0}(x_n))}{\sum_{n=1}^{r} (\prod_{n=1}^{r} \delta_{0}(x_n))}
\]

where $C = \frac{1}{\Delta v}$ is the normalization coefficient, $\Delta v$ is the magnitude of the output of the on-line adaptive ADRC
controller1; $\delta^{0}$ is the semi-coefficient of responsibility.

As it is reasonable that the magnitude of ADRC rules shows its responsibility to the output error of the current state,
the adaptive ADRC system makes change to each rule by ADRC controller 1 based on responsibility coefficient.

3. Soft System of Small unmanned helicopters

We designed the software system of the flight control system of the SUAV such as Figure 4.

In software architecture, the flight control system follows a two cascade controller design with an inner and outer
controller.

The inner loop control system is attitude controller which is composed of three SISO ADRC controllers: pitch ADRC,
roll ADRC and yaw ADRC. The attitude controller is most important part of the software system because that the attitude of
SUAV is the fundament of the moment of the SUAV. For example, if the SUAV wants to fly ahead, it must low the head,
in other words, decreasing the pitch angle. So all instability characters of SUAV focus on the attitude of the SUAV that is also the reason that the inner loop control system adopts the adaptive ADRC control arithmetic.

Based on the inner loop controller system, the outer loop controller, navigation control system, is composed of three SISO PID controllers: trajectory controller, altitude controller and speed controller. The outer loop controller get the command from the position controller.

![Diagram of flight control system](image)

**Fig.4. Proposed software architecture of the flight control system.**

### 4. Experiment

Finally, in order to verify the control algorithm ADRS, in this paper, experiment on the mini unmanned helicopter, ultra-compact underwater robots, robotic systems, have achieved good results. Parts of the mini unmanned helicopter, the actual flight test data shown in Figs. 5-6.

![Data of pitch channel](image)

**Fig.5. Data of pitch channel of SUAV system.**

![Data of roll channel](image)

**Fig.6. Data of roll channel of SUAV system.**

In the data graph of Fig. 5 and Fig. 6 the red solid lines represent the target attitude angle and the blue dotted line represents the actual attitude angle. From the data can see: the design of the control system based on adaptive self-
disturbance rejection controller has good static and dynamic performance. Adaptive ADRC controller fully meets the needs of the ultra-small unmanned helicopter robot control system.

5. Conclusion

Small UAV flight attitude control process has strong time-varying characteristics, and there are random disturbances. The conventional control methods with unchanged parameters are often unworkable. An on-line adaptive ADRC control system is designed. An on-line adaptive ADRC system implements a simultaneous on-line tuning of ADRC rules. The flight experiment showed that the proposed adaptive ADRC system provides quicker response, smaller overshoot, higher precision, robustness and adaptive ability. It satisfies the needs of autonomous flight of small UAV.

Acknowledgements

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References