Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-17 (2016) 118–123

Vision-based control for helicopter ship landing with handling qualities constraints

Quang Huy TRUONG*. Thomas RAKOTOMAMONJY.**
Armin TAGHIZAD*. Jean-Marc BIANNIC******

** ONERA (The French Aerospace Lab), BA701, Salon-de-Provence, 13661 France*
(Tel: +334-90-17-01-39; e-mail: quang_huy.truong@onera.fr).
***ONERA (The French Aerospace Lab), BA701, Salon-de-Provence, 13661 France*
(e-mail: thomas.rakotomamonjy@onera.fr)
****ONERA (The French Aerospace Lab), BA701, Salon-de-Provence, 13661 France*
(e-mail: armin.taghizad@onera.fr)
*****ONERA (The French Aerospace Lab), 2 avenue Edouard Belin, BP 74025, Toulouse cedex, 31055 France*
/ Department of Control Engineering, ISAE, 31055 France (e-mail: jean-marc.biannic@onera.fr)

Abstract: In combination with an IBVS control system, two types of advanced helicopter control laws are introduced in this paper with a complete tuning procedure, and compared. The controllers are used to follow and land on a ship. In this approach the procedure is set as fully automatic, but as the final goal is to provide the pilots with an assistance based on these controllers, an eye is kept on flying and handling qualities of the closed loop helicopter. Therefore controllers are tested to assess stability, robustness and flying characteristics. Models include helicopter and ship dynamics, actuators, and embedded camera.

Keywords: Helicopter dynamics, navigation, guidance, control theory, target tracking, vision based navigation, autonomous landing, handling and flying qualities

NOTATIONS

u, v, w	Helicopter velocities (in body frame)
p, q, r	Body-axis angular rates
Φ, θ, ψ	Helicopter Euler angles
x, y, z	Helicopter position (NED coordinates)
δ_{col}, δ_{lat}, δ_{lon}, δ_{ped}	Primary helicopter control inputs

1. INTRODUCTION

Landing an air vehicle on a ship is a difficult task due to natural constraints such as singular wind (ship air wakes), ship induced movements (from sea waves) and variable visibility (Taghizad and al., 1998). For helicopter missions those elements are even more important as the time necessary to proceed is much longer than with aircrafts.

1.1 Techniques for tracking and landing

Various studies focus on that issue for helicopters and other Vertical Take-Off & Landing vehicles, and combine methods to track and land safely on a ship.

(Oh and al., 2006) uses a tether to guide the autonomous landing. Some studies predict ship deck movements for calm opportunities detection (Fourie and al., 2015) or automatic tracking and landing (Horn and al., 2015). Visual servoing is one of the most promising techniques. It is defined through two main approaches: Image-Based Visual Servoing (IBVS) and Position-Based Visual Servoing (PBVS), depending upon whether the control uses directly image features (IBVS) or estimate the target pose before (PBVS) (Chaumette and al., 2006), (Chaumette and al., 2007). PBVS often uses vision alone (Yu and al., 2007) to measure the height between a UAV and the ground with 3D vision. (Hu and al., 2015) goes further with a moving platform whose dynamics is measured then predicted by vision. (Sanchez-Lopez and al., 2014) estimates the pose of a 6-DOF moving platform with known dimensions, for various sea states. Other methods combine vision with inertial measurements (Ceren and Altug, 2009) or GPS (Saripalli and al., 2003). IBVS control schemes are also used with UAVs: in (Herissé and al., 2011) optical flow and inertial measurements are combined to track and land on a moving platform, in (Ceren & Altug, 2009) IBVS methods from (Chaumette and al., 2006) are combined with inertial measurements and Proportional Derivative (PD) controllers for Attitude Control (AC), in order to visually control a quadrotor above a static target. Advanced control laws for attitude control, rate control or velocity control are common for modern helicopters and can be combined similarly. The control schemes compared in this paper are inspired by the methods explained in this last reference.

1.2 Ship landing: many possible responses

Constraints related to ship landing are defined by so many criteria that standards for rotorcraft flights such as ADS-33E-PRF (Baskett and al., 2000) do not define flying and handling qualities (FQ and HQ) for maritime manoeuvres. As a result it is difficult to define one elementary mission task element (MTE) with general handling qualities despite several studies such as (Padfield and al., 1997). For each MTE, handling qualities usually require specific piloting response-types, depending on the context. In this particular case, pilots mainly rely on experience to assess the needed response, hence control type. As a result there is no unique design brief for ship

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.09.021

landing, and being able to track and land onto a moving target like a ship deck under high sea conditions is a real challenge for maritime missions, and helicopters need different agile control laws.

1.3 Objectives

This paper presents a method to set two controllers based on a Translational Rate Command (TRC) law, a common advanced speed control law for modern helicopters. The main goal is to follow a ship and land on it, using image features as references while filtering its movements to get a smooth and realistic helicopter trajectory compared to the targeted ship. Due to the several possible situations and FQ constraints two TRC controllers are defined in order to give a choice to pilots, depending on their needs (in response-type) in terms of HQ/FQ requirements:

- AC-based TRC: uses an inner AC loop
- RC-based TRC: uses an inner Rate Control (RC) loop

Controllers are built with PID controllers. The first AC-based TRC structure is suggested by HQ requirements for TRC systems, based on (Dudgeon & Gribble, 1996). The RC-based TRC is inspired by this idea, but adapted. RC, AC and TRC are usually set to be directly commanded by the pilot's control sticks – then controls are known as ACAH (Attitude Command, Attitude Hold) and RCAH (Rate Command, Attitude Hold) in standards. Each law has an influence on one specific order dynamics, which means the effect – depending on the chosen law – is a trade-off between being slow and stable or fast and easily unstable. Here these laws are set as automatic (without pilot inputs), but the final purpose is to provide optimal commands to be followed by pilots for ship tracking and landing, as part of a research project led at ONERA. Tools are given to tune these systems based on required flying qualities.

2. THE CLOSED LOOP CONTROL SYSTEMS

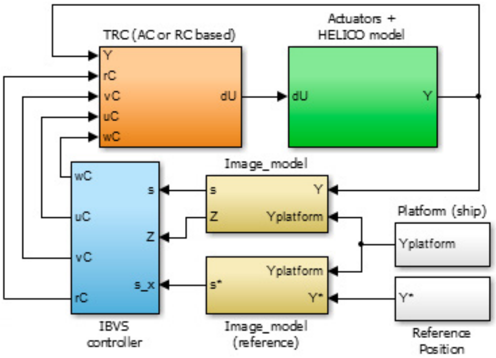

Fig. 1. General architecture, AC or RC-TRC

For both cases, the general architecture is presented in Figure 1 as a cargo-type, 11-ton helicopter model with actuators (in green), cameras that project target poses onto image planes (in yellow), a TRC (in orange) and an IBVS controller (in blue), based on the concepts explained in (Chaumette and al., 2006). Ship current and objective (reference) positions are used as inputs.

2.1 Models and assumptions

For this study the dynamic system uses four input commands δU from the actuators, corresponding to instructions coming from collective and cyclic sticks, and pedals. Helicopter dynamics was linearized around an equilibrium state X_E to get a state space system $\delta\dot{X} = A\delta X + B\delta U$ as described in (Padfield, 2007). This X_E is chosen following the desired translational speed: the ship average speed. Measurements Y include the state $X = \delta X + X_E$ and some derivatives, without noise. The main variables are described in Table 1.

Table 1. Input command δU and state δX

Variable	Notations
δU	$[\delta_{col}\ \ \delta_{lat}\ \ \delta_{lon}\ \ \delta_{ped}]^T$
δX	$[\delta u\ \ \delta v\ \ \delta w\ \ \delta p\ \ \delta q\ \ \delta r\ \ \delta \Phi\ \ \delta\theta\ \ \delta\psi]^T$

Actuators model takes into account delay (around 10 ms, modelled through a first-order filter), and saturation. Ship helideck displacements were modelled along the x, y, Φ and θ axes, from data given in (Horn and al., 2015).

Initial state: The simulation starts from a given equilibrium condition, with a small horizontal relative speed compared to the ship, and close enough so that the helicopter camera can see the ship helideck from above. That camera is positioned high at the front of the rotorcraft, so that it can watch most of the ground points once landed.

2.2 TRC controllers

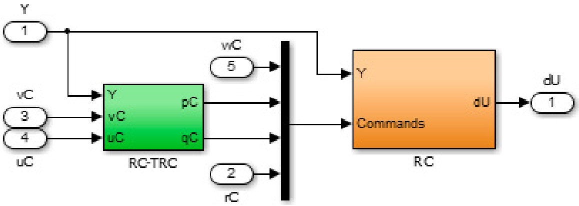

Fig. 2. RC-TRC architecture (Simulink view) – AC-TRC is built in a similar way

Both TRC include an inner loop and an outer loop, all based on Proportional Integral and Derivative (PID) controllers. PID controllers are simple and can be set to reduce cross couplings that naturally exist with helicopters, as used in (Antonioli, 2014). His method developed to set PID gains for an AC law, in order to get expected HQ and FQ and reduce couplings, is used here to set AC gains. For each law, each controller sets its inputs/outputs as shown in Table 2.

Table 2. Inputs/Outputs of AC/RC/TRC controllers

Law	Inputs					Outputs
AC	*Measurements*	w	$\delta\phi, p$	$\delta\theta, q$	r	$\delta_{col}, \delta_{lat},$ $\delta_{lon}, \delta_{ped}$
	Commands	w^c	$\delta\phi^c$	$\delta\theta^c$	r^c	
RC	*Measurements*	w	p	q	r	$\delta_{col}, \delta_{lat},$ $\delta_{lon}, \delta_{ped}$
	Commands	w^c	p^c	q^c	r^c	
AC-TRC	*Measurements*	u		v		$\delta\phi^c, \delta\theta^c$
	Commands	u^c		v^c		
RC-TRC	*Measurements*	u		v		p^c, q^c
	Commands	u^c		v^c		