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***Abstract*— In this paper, a tracking controller is designed for a helicopter with a slung load. The designed controller is nonlinear and is based on the backstopping method. First, we developed a comprehensive nonlinear mathematical model of the helicopter and designed a nonlinear backstepping controller to track the trajectory of the helicopter alone. Then, we developed a mathematical model of the slung load and integrated it with the helicopter system. In the next step, we designed an anti-swing delayed feedback controller to damp the load oscillation. This controller works independently of the nonlinear tracking controller. Moreover, its performance is optimized using the differential evolution (DE) technique. The simulation results show the effectiveness of the designed control system.**

***Index Terms*—helicopter slung load system, backstepping nonlinear tracking control, delayed feedback, anti-swing controller, differential evolution**

I. INTRODUCTION

Autonomous vehicles have gained significant attention for use in civil and military applications over the recent past. Helicopters are the most suitable option for usage during operations, which require vertical take-off and landing and hover capabilities [13]. Unfortunately, they are complex, nonlinear and dynamically unstable flying vehicles and are difficult to control. Therefore, a stabilizing controller for helicopters is necessary.

The first stage of designing a controller is to develop a mathematical model that represents the behavior of the system to be controlled appropriately. The complexity of the helicopter dynamics compels the user to obtain a model that gives provides a good balance between accuracy and simplicity [12, 14, 15]. Considering the flexibility of the rotors and fuselage and the full dynamics of the engines and actuators, a detailed and highly accurate model for the helicopter may be obtained. However, this model will be extremely complicated [11].

There are two common approaches for the mathematical modeling of helicopters, which are physics-based model development and systems-theory-based model development [13]. In the physics-based approach, the dynamic behavior of the system is modeled by applying the basic laws of mechanics. Conversely, the systems-theory-based model is built by using system identification methods based on collecting input-output data, disregarding any knowledge about the physics of the system. This approach is difficult since observing the individual effect of each control input of the helicopter is not possible because the pilot must apply a combination of the inputs in flight operations. Thus, to address this problem, certain specific maneuvers of the helicopter are performed in which the helicopter movement is limited to one degree of freedom [16]. Additionally, this approach requires special measuring instruments for the collection of in-flight input-output data [11, 17].

Several model-based and non-model-based approaches exist in the literature for the control design of the helicopters, and a good survey of these models is given in [11]. Most control designs for helicopter flight control has been linear. In recent years, the subject of nonlinear controller design has gained interest, and it has been aided theoretically by the appreciation of the helicopter control problem. Koo and Sastry [10] show that exact input-output linearization is not applicable for helicopters, and it causes unstable zero dynamics. This results in the inapplicability of many of the nonlinear controller design methods for helicopters. However, a solution to this is also suggested by using an approximate dynamic model. The approximate model is obtained by neglecting the effect of the main rotor tilt on the translational motion of the helicopter. As a result of this approximation, the dynamic equations of the system appear in a feedback form, which makes the backstepping control design most suitable for it. For helicopters, the backstepping controller has been designed in [4-5, 18-21].

In this paper, we derived a nonlinear model of the helicopter with an analytical approach based on first-principles modeling. A good balance between accuracy and simplicity is achieved by making some assumptions about the system [5, 12], details of which are mentioned in the forthcoming sections. The main contribution of this paper is the design of a nonlinear tracking controller for a helicopter slung load system. This task is achieved in two steps. Using the approach of [4-5], a backstepping controller is designed for the helicopter alone in the first step. The anti-swing controller for the load is designed in the second step, based on the delayed feedback method [8, 14], and is tested on the integrated system.