Variable length sling load hoisting control method

Austin Morock*, Andrea Arena**, Mary Lanzerotti***, Jacob Capps*, Walter Lacarbonara**

*Department of Civil and Mechanical Engineering, United States Military Academy, West Point, NY, USA

**Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, Italy

***Department of Physics and Nuclear Engineering, United States Military Academy, West Point, NY, USA

Abstract. This work proposes a variable length sling load hoisting towards the control of oscillations and stabilization of MEDEVAC single-point sling loads. In the context of variable sling length control methods, a control law is sought that dampens the oscillations during hoisting of a low-mass sling load. This work discusses a method using initial sling length, a time step, and a desired final sling length to obtain a control law for these parameters. An initial proof of concept of the proposed control strategy is provided, and stability of the proposed approach is being investigated.

Introduction

Currently, whenever cargo transport is desired or a medical evacuation (MEDEVAC) is needed, a sling load is incorporated. A proper sling load maneuver comprises the helicopter achieving a hover, picking up the load or patient, moving to a desired location and either attaining a hover again if the load is cargo or landing if it is a MEDEVAC patient. At any point in the hoisting process, external forces and internal inputs such as pilot or flight computer control inputs and wind loads can affect the stability of the payload. If these oscillations are too large, the load may be cut. This is not feasible for MEDEVAC hoists, which could create a dangerous situation dangerous for the aircraft and the crew. Currently, the common solution to such large-amplitude oscillations is the crew chief of the aircraft grabbing the sling and attempting to stabilize the payload motion. This is an extremely dangerous maneuver and is contingent on the crew noticing the oscillations in time. If a crew member does not observe the swinging load, the cable could strike the helicopter, resulting in essentially a pulse input into the controls, which could create unrecoverable conditions, likely resulting in a crash if the pilot cannot recover properly. For this reason, there is a need for a reliable sling load stabilization system that can effectively dampen low mass, lightly damped sling load oscillations [1]-[4].

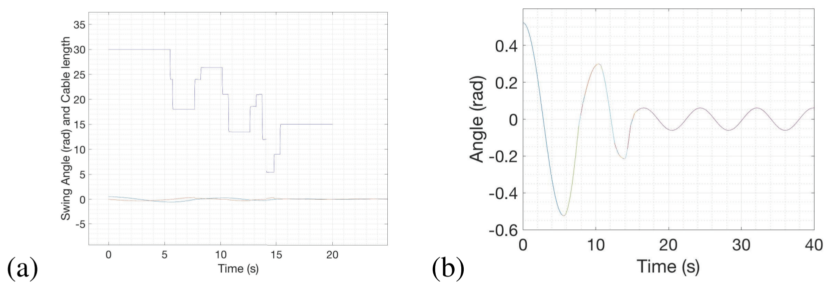

Figure 1: Preliminary results studied in MATLAB for a UH-60M helicopter rescue with initial length $l(t_\mathrm{a}) = 30.$ m, $b = 90\ \frac{1}{\mathrm{s}}$, $\theta_0 = \frac{\pi}{60}$, $\dot{\theta}_0 = 0$, $t_\mathrm{a} = \sqrt{30.}$ s; $t_\mathrm{b} = 1.02\sqrt{30.}$; $t_\mathrm{ab} = \frac{(t_\mathrm{b}+t_\mathrm{a})\sqrt{30.}}{2}$; $t_\mathrm{c} = 1.04\sqrt{30.}$; $t_\mathrm{d} = 1.06\sqrt{30.}$; $t_\mathrm{cd} = \frac{(t_\mathrm{c}+t_\mathrm{d})\sqrt{30.}}{2}$.

Results and Discussion

We consider the planar pendulum with variable length $l(t)$ under gravity, g, with the small angle approximation such that $\ddot{\theta} + \frac{2\dot{\theta}\dot{l}}{l} + \frac{g}{l}\theta = 0$ [5]. An overdamped solution, $\theta(t) = A_1 e^{-\mathrm{b}t}$, is substituted into the second order differential equation to obtain a first order differential equation for the length, $\dot{l} - \frac{\mathrm{b}l}{2} - \frac{g}{2\mathrm{b}} = 0$. This first order differential equation is solved to obtain a sling length control law for $l(t)$ such that $l(t) = \left[l(t_a) + \frac{g}{\mathrm{b}^2}\right] e^{\frac{\mathrm{b}}{2}(t-t_\mathrm{a})} - \frac{g}{\mathrm{b}^2}$, where $l(t_\mathrm{a})$ is the length at time $t = t_\mathrm{a}$. We can set $l(t_\mathrm{b})$ to represent the cable length at time $t = t_\mathrm{b}$ and $\Delta t = t_\mathrm{b} - t_\mathrm{a} = t_\mathrm{ab}$, to obtain $l(t_\mathrm{b}) = \left[l(t_\mathrm{a}) + \frac{g}{\mathrm{b}^2}\right] e^{\frac{\mathrm{b}}{2}(t_\mathrm{b}-t_\mathrm{a})} - \frac{g}{\mathrm{b}^2}$. We introduce a piecewise linear function for the cable length at time intervals $\{t_\mathrm{ab}, t_\mathrm{cd}, \cdots,\}$ that increase and decrease the cable length. Figure 1 shows preliminary results for swing angle and length for $l(t_\mathrm{a}) = 30.$ m, $b = 90.$, $\theta_0 = \frac{\pi}{60}$, $\dot{\theta}_0 = 0$, $t_\mathrm{a} = \sqrt{30.}$ s.

References

[1] David T. Liu, *In-flight stabilization of externally slung helicopter loads*, USAAM-RDL Tech. Rep. 73-5. Northrop Corp., Electronics Div., Hawthorne, CA, 1973.

[2] L. S.Cicolani, C. Ivler, C. Ott, R. Raz, and A. Rosen, “Rotational Stabilization of Cargo Container Slung Loads,” *J. Am. Helicopter Soc*. 60, 042006-1-042006, 2015.

[3] A. Arena, W. Lacarbonara, A. Casalotti, “Payload oscillations control in harbor cranes via semi-active vibration absorbers: modeling, simulations and experimental results,” *Procedia Engineer*. 199, 501-509, 2017.

[4] A. Morock, A. Arena, M. Lanzerotti, J. Capps, B. Huff, W. Lacarbonara (2020) “Active sling load stabilization”. Proceedings of the First International Nonlinear Dynamics Conference (NODYCON 2019), *Nonlinear Dynamics and Control* - Vol. II, pp. 129-136.

[5] A. Bockstedte and E. Kreuzer, “Crane Dynamics with Modulated Hoisting,” *Proc Appl. Math. Mech.*, 5, 83-84, 2005.