An open software - open hardware lab of the air levitation system

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Abstract: Virtual, remote and hands-on experimentation can be equally important and interesting for students of control engineering. This work presents a low-cost, open-based lab implementation of the air levitation system that can be easily developed in all the previous forms.

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1. INTRODUCTION

It has been said that the automatic control discipline is mainly based on two streams of thought (Kheir et al., 1996). The first one would be practical experience, while the second one would be theory and mathematics. Nowadays, few people would discuss that control engineers need to have both a wide experience implementing solutions in real problems and plants and a deep understanding of the mathematics and theory behind these solutions. The first stream, the one based in practical experience, relies on the idea that something needs to be controlled and so, control systems engineering curricula should be based on hands-on and practice experiences. While this has been the traditional vision of engineering, it started changing around one hundred years ago, when the second stream, the one based in theory and mathematics, started to gain importance (Froyd et al., 2012). This one, relies on learning and understanding abstract concepts, such as the four identified by (Kheir et al., 1996) as the major ones on control systems: stability, feedback, dynamic system, and dynamic compensation. Therefore, reaching a balance between theoretical proofs and physical intuition is a major challenge in control education. Lab experimentation plays a key role as a way to connect theory and practice. Among others, lab experience helps fulfilling the following goals (Antsaklis et al., 1998):

- Introducing students to real world modeling and/or control issues, such as uncertainties, saturation, noise, sensor/actuator dynamics, etc.
- Demonstrating, validating and/or motivating analytic concepts.
- Providing facility with instrumentation and measurement tools.
- Team learning and problem solving.
- Exposing students to broader design issues, from problem specification to hardware implementation.
- Developing professional practices, including maintaining engineering notebooks and report writing.
- Comparing theoretical results with real world results so that the theory can be validated.

Traditional hands-on labs entail high costs related with space requirements, equipment, and maintenance staff (Gomes, 2009). For the last twenty years there has been a line of research that looks for reducing lab costs by taking advantage of the Internet, i.e., by replacing hands-on labs with online ones.

In order to characterize the different approaches for experimentation practices, two criteria were proposed in (Dormido, 2004):

1. According to the way resources are accessed for experimental purposes, environments can be either local or remote.
2. According to the physical nature of the lab, environments can be either real or simulated plants.

The combination of the two previous criteria gives us a categorization of the existing possibilities for experimentation:

1. Local access-real resource. This situation represents traditional hands-on labs, where students are in front of the real plant.
2. Local access-simulated resource. In this combination, the whole experimental environment is software, and the experimentation interface works with a simulated/virtual resource.
3. Remote access-real resource. In this case, a real plant is accessed through the Internet. Students remotely operate and control a real plant through an experimentation interface. This approach is typically named ‘remote lab’.
4. Remote access-simulated resource. The last form of experimentation is similar to the previous one, but it replaces the physical system with a mathematical model. This approach is typically known as ‘virtual lab’.

As the technology has progressed and some of the major concerns related to Virtual and Remote Labs (VRLs) have been solved over the recent years, their importance and use have been growing (Heradio et al., 2016; de la Torre et al.,...
the downwards effect of the gravity (second term in the
represented by the arrow going upwards in Fig. 1), and
flow (given by the first term in the right part of Eq. 1 and
the levitating object are be the upwards effect of the air
Jernigan et al., 2009). Since the only forces acting over
previous works (Timmerman and van der Weelea, 1999;
air levitation system, which has been studied by several
Newton’s second law gives us the dynamic equation for the
system. Section 4 presents some experiences that
can be performed with the developed lab. Finally, Section
the software applications for the real and virtual operation
of the system. Section 4 offers the
guidelines for building the experimental setup and shows
resources, the virtual and remote laboratory can be found
system. For those readers that might be interested in these
lab. The authors have also developed a simulation of the
adopted to be used as both a remote lab and as a hands-on
Given the complementary uses of the previous experimen-
tation approaches, it is probably best if an experiment
itself is offered in several ways. This work presents a
low-cost lab implementation of an air levitation system,
based in open solutions. Thanks to this, it can be easily
adopted to be used as both a remote lab and as a hands-on
lab. The authors have also developed a simulation of the
system. For those readers that might be interested in these
resources, the virtual and remote laboratory can be found in
UNILabs, a network of interactive online laboratories.
For those readers interested in building the system to use it
as a hands-on lab, the main instructions and tips to do so
are given in this paper. The model of the air levitation
system is presented in Section 2. Section 3 offers the
guidelines for building the experimental setup and shows
the software applications for the real and virtual operation
of the system. Section 4 presents some experiences that
can be performed with the developed lab. Finally, Section
5 contains the conclusions of this work.

2. THE SYSTEM

Newton’s second law gives us the dynamic equation for the
air levitation system, which has been studied by several
previous works (Timmerman and van der Weelea, 1999;
Jernigan et al., 2009). Since the only forces acting over
the levitating object are be the upwards effect of the air
flow (given by the first term in the right part of Eq. 1 and
represented by the arrow going upwards in Fig. 1), and
the downwards effect of the gravity (second term in the
right part of Eq. 1 and represented by the arrow going
downwards in Fig. 1):

\[ m\ddot{z} = F = \frac{1}{2} C_d \rho A (v_\text{w} - \dot{z})^2 - mg. \] (1)

Where:

- \( m \) is the mass of the object to levitate.
- \( z \) is the vertical position of the object in the tube.
- \( \rho \) is the density of air.
- \( A \) is the objects area exposed to the upwards air flow.
- \( v_\text{w} \) is the velocity of the air inside the tube.
- \( g \) is the gravity.
- \( C_d \) is the so-called drag coefficient.

The drag coefficient is a term that depends on Reynold’s
number, which, in turn, depends on the relative velocity
between the object that moves inside a flow and the
velocity of such flow. For small velocities as the ones
considered here, one can assume that \( C_d \) is constant. In
that case, we can express Eq. 1 in terms of a constant
named \( \alpha \), being: \( \alpha = \frac{1}{2} C_d \rho A \):

\[ \ddot{z} = \frac{\alpha}{m} (v_\text{w} - \dot{z})^2 - g. \] (2)

Now, the levitating object will be in steady state when it
does not move, this is, when \( \ddot{z} = \dot{z} = 0 \). Let us call \( v_\text{eq} \)
the air speed at such equilibrium point. Then:

\[ g = \frac{\alpha}{m} v_\text{eq}^2. \] (3)

Therefore, we can finally express the dynamic equation like
this:

\[ \ddot{z} = g \left( \left( \frac{v_\text{w} - \dot{z}}{v_\text{eq}} \right)^2 - 1 \right). \] (4)

2.1 Linearization

As Section 4 will show, the virtual lab features both the
linear and the nonlinear models. Linearization for this
system is pretty straightforward. Let \( x = \frac{v_\text{w} - \dot{z}}{v_\text{eq}} \).
Then, Eq. 4 is of the type \( f = g(x^2 - 1) \), and it can be easily linearized
around the equilibrium point \( (v_\text{eq} = v_\text{w} - \dot{z}, \text{or } x = 1) \) using
Taylor’s approximation \( (f(x) \approx f(1) + f'(1)(x - 1)) \):

\[ \ddot{z} = 2g(x - 1) = \frac{2g}{v_\text{eq}} (v_\text{w} - \dot{z} - v_\text{eq}). \] (5)

3. THE LAB

Based on the low-cost and open source paradigms, several
requirements were established to be satisfied by the remote
lab design:

- The design should be as low-cost as possible (under
  1008), so it will be affordable not only for universities,
  but also for students in case they would want to have
  their own experimentation platform.
- The design should be easily replicated, so that any
  educator with basic programming knowledge will be
  able to build one.
- It should use open-source technologies. This require-
  ment has the twofold purpose of reducing cost to meet
  the first requirement, but also because this approach
  encourages to acquire knowledge by tinkering with

Fig. 1. Balance of forces acting over the levitating object.
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