# The Michelson Interferometer: a learning object

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***Abstract*—The Michelson interferometer, based on the interference of two monochromatic light beams, is the basis of the working principle of systems used as primary standard in national standards laboratories all over the world. With these techniques it is possible to measure up to 100 m with a resolution of 300 nm and, with higher system complexity, it is possible to achieve accuracies of nanometres. Here, we report on a learning object that provides the theoretical and practical framework needed for understanding how the interferometer works, using written or web seminar tutorials, plus the remote access to a real interferometer and the use of 2D and 3D simulations. These were developed to help students understand the interference phenomenon, the fringe patterns, the method for measuring displacement and how to fine tune and use an interferometer.**

***Index Terms*—Learning object, Michelson interferometer, remote laboratory, virtual laboratory.**

## I. INTRODUCTION

Displacement is an important physical quantity in many areas, such as engineering, science, metrology, astrophysics, etc.

The measurement of displacement is also fundamental for the work of a significant number of automated systems as well as for the calibration and control of many machine tools.

For small displacements where measurements with micro accuracies are needed [1], a laser beam is used for counting the number of wavelengths within the displacement. A Michelson interferometer with iodine stabilised laser is used as the system traceability to the SI unit of length [2] in metrological laboratories.

At the Physics Engineering Department of the Faculty of Engineering, University of Porto (FEUP), there is a Michelson-Morley interferometer. Considering the interest of making such unfamiliar equipment available to students of several engineering, science and metrological areas, this work aimed at allowing the use of this equipment anytime, anywhere, by remote access via web, and adding several additional teaching/learning materials [2].

Figure 1 shows the interferometer at its initial stage, when it was just a set of bits and pieces: a granite block with plane surfaces was placed on a table and between both a pressurized car wheel inner tube was used as an anti-vibrating interface. The interferometer components were placed over the upper granite block surface.

Using such set-up did require constant tuning procedures, contributing for excessive time wasting whenever the students faced this unfamiliar and sophisticated equipment. As a consequence the interferometer was not frequently used.

For making this equipment available at any time to any student at FEUP (or at any other place) the outcome of a small project produced the final set-up shown in figure 2. The granite block is placed directly over a table and supports a Bosch Rexroth aluminium profile frame. Its considerable mass brings stability to the system protecting it from inconvenient vibrations. The profile characteristics provide a flexible way to fix all the components.

At present the system is standing alone and working properly by remote actuation since September 2006 without any special maintenance.

A network camera, a basic model from Axis with its own IP address, is used as a stand-alone unit for capturing live video streams with high image quality. Room lighting is switched on every time the system is remotely accessed for improving the quality of the image. The working life of the interferometer is protected by switching it off after operation.

Figure 1. Michelson Interferometer – initial stage

Figure 2. Michelson Interferometer – current stage

## II. EXPERIMENTAL SET-UP

### A. The Michelson Interferometer

This system permits the user to measure displacements with the resolution of one half of the laser emission wavelength according with the Michelson interferometer working principle. The set-up uses a Helium Neon laser from JDS with a wavelength of 632.8 nm. This means that the intrinsic measurement resolution of the system is 316.4 nm. Better resolution would be possible with an elaborate data processing of the fringe counting. As an example the NPL calibration service offers an uncertainty of 0.05 µm with a range of up to 50 mm [3].

### B. Mechanical interface

Several mechanical interfaces were designed allowing accurate positioning of overall system components for a rigorous setting of the interferometer, figure 3.

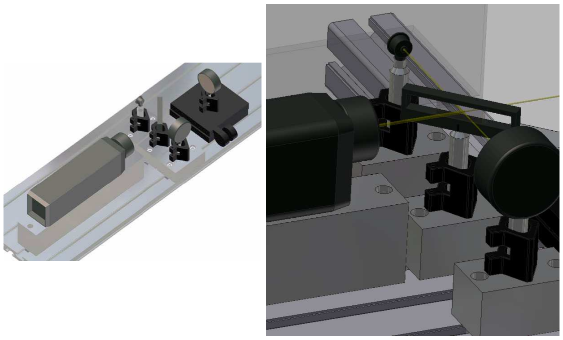


Figure 3. Mechanical assembly

### C. Hardware interface

A high-performance crossed-roller bearing linear stage (NRC-M-426 from Newport) combining high-resolution movement, low run out, and large load capacity, was used for motion guiding of the sliding mirror. The stage is moved by a piezo stepping motor (PZA12 from Newport) allowing a stable motion range that ensures 30 nm of displacement resolution with no loss of position when power is cut off. A controller unit (Nano PZ DSE3 from Newport) with communication interface links to a PC for computer control.

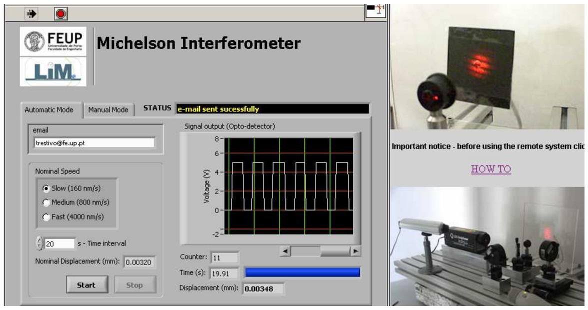
A photodiode with an integrated operational amplifier, ref OS15K, is used for fringe counting when connected to a timing and digital I/O PCI card.

### D. Software interface

The application for remote control of the sliding mirror displacement is based on LabVIEW 7.1 and the user interface is shown in figure 4.

The user interface has selectable parameters and information outputs of numeric and graphical type. On the upper right corner the live video shows the fringes behaviour when a displacement is imposed. On the lower right a picture of the real set-up is shown giving the user a more real perception of the system.

There are two modes of actuating the interferometer, manual and automatic, figure 4.



STATUS e-mail sent sucessfully

email: trestivo@fe.up.pt

Nominal Speed

● Slow (160 nm/s)
○ Medium (800 nm/s)
○ Fast (4000 nm/s)

20 s - Time interval

Nominal Displacement (mm): 0.00320

Counter: 11

Time (s): 19.91

Displacement (mm): 0.00348

Important notice - before using the remote system clic

Figure 4. User interface – automatic mode

The user may choose a velocity value for the sliding mirror. He (she) may also introduce an email address for receiving data from the test. With the test data available the user should be able to calculate the laser beam wavelength. The visualization of the fringe movement is also possible through the graphical window.

The manual actuation mode allows the user to freely move the sliding mirror forward and backward by incrementing the piezo stepping motor by 30 nm steps. This can be observed either on live video by perceiving the sliding fringe movement or on the graphic representation of the output state of the high gain amplifier photodiode.

## III. VIRTUAL LABORATORY

Two simulations have been developed for improving the users' comprehension of the light interference phenomenon [4].

The 2D simulation, implemented in Macromedia Flash, outlines the working principle of the interferometer, as well as some aspects of light interference, figure 5. The simulation explains why the light fringe pattern occurs, showing the various physical causes and allowing the student to interact with it.

The 3D simulation, using C++ and the OpenGL graphic library, presents the Michelson interferometer with a high level of realism. It achieves a sophisticated degree of interactivity and permits a good perception of many parameters that are relevant when using a real system, figure 6.

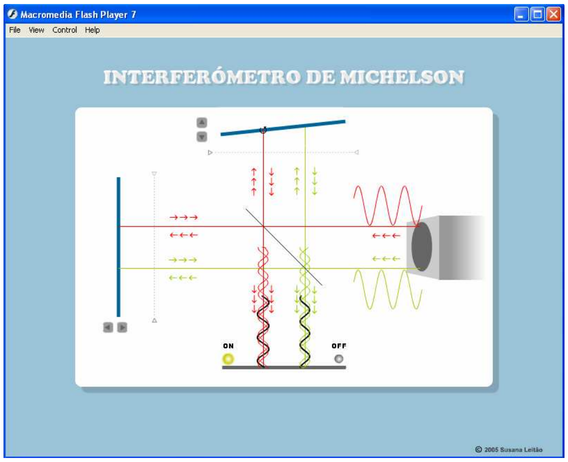


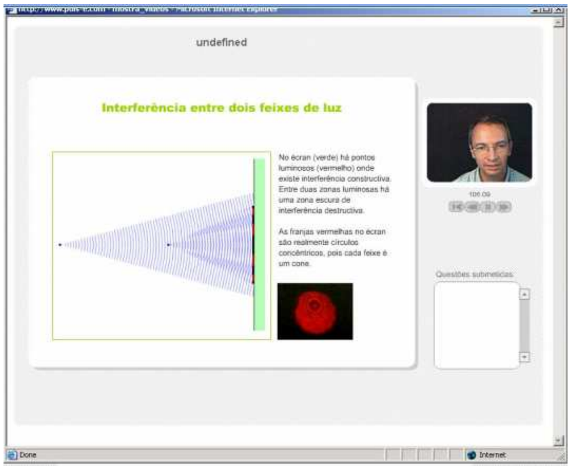
Figure 5. 2D simulation

Figure 6. 3D simulation

The user may perform the complete procedure for tuning the interferometer before using it for displacement measurement. He (she) may switch on and off the laser, choose the laser beam wavelength (this means selecting the laser!), rotate the splitter (fine tuning), select the source light (point source or infinite), move the sliding mirror and magnify the fringe pattern. The simulator also offers three different perspectives for observing all the system and the interference pattern with zoom facilities. Tuning the real system is a step difficult to understand for students. After having trained it virtually the students will be facing a Michelson Interferometer with familiarity.

Other multimedia materials also integrate the learning object.

A web seminar with a few animations explains the interference phenomenon avoiding analytical treatment, figure 7.



Interferência entre dois feixes de luz

No écran (verde) há pontos luminosos (vermelho) onde existe interferência constructiva. Entre duas zonas luminosas há uma zona escura de interferência destructiva.

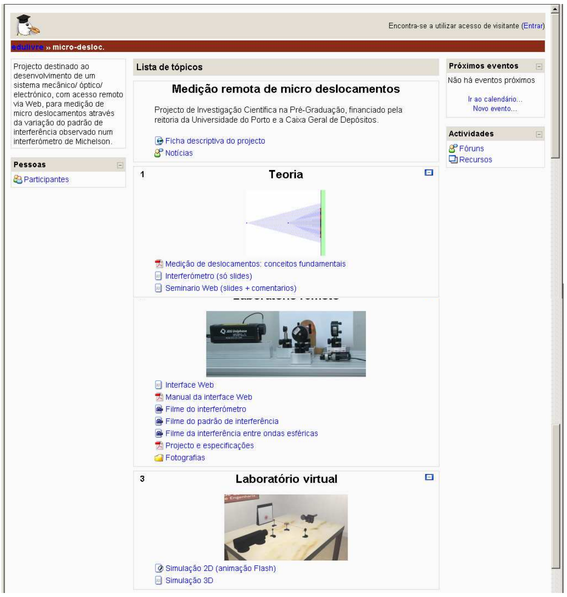
As franjas vermelhas no écran são realmente círculos concêntricos, pois cada feixe é um cone.

Figure 7. Web seminar

A set of movies demonstrates the different light patterns. The linear pattern is visible when operating the remote system. The circular pattern requires more precise tuning of the interferometer and more accurate optoelectronic hardware.

Other tutorial materials are also supplied covering theoretical concepts related with position, displacement and distance, mechanical design of the system and project description.

All the materials in this learning object are on a Moodle platform using the structure of a generic course, figure 8.


Encontra-se a utilizar acesso de visitante (Entrar)

edulivre » micro-desloc.

Projecto destinado ao desenvolvimento de um sistema mecânico/ óptico/ electrónico, com acesso remoto via Web, para medição de micro deslocamentos através da variação do padrão de interferência observado num interferómetro de Michelson.

Pessoas
- Participantes

Lista de tópicos

Medição remota de micro deslocamentos

Projecto de Investigação Científica na Pré-Graduação, financiado pela reitoria da Universidade do Porto e a Caixa Geral de Depósitos.

- Ficha descriptiva do projecto
- Notícias

1 Teoria
- Medição de deslocamentos: conceitos fundamentais
- Interferómetro (só slides)
- Seminario Web (slides + comentarios)

- Interface Web
- Manual da interface Web
- Filme do interferómetro
- Filme do padrão de interferência
- Filme da interferência entre ondas esféricas
- Projecto e especificações
- Fotografias

3 Laboratório virtual
- Simulação 2D (animação Flash)
- Simulação 3D

Próximos eventos

Não há eventos próximos

Ir ao calendário...
Novo evento...

Actividades
- Fóruns
- Recursos

Figure 8. The learning object

## IV. PEDAGOGICAL DISCUSSION

During the last decade there has been an intensive growth of information technology as a teaching and learning device [5], particularly – if not exclusively – in the field of engineering [6-8]. The relevance of technology-based tools in engineering might be even more significant given the fact that “the control of a remote laboratory in a classroom is very similar to the controls of robots used in remote manufacturing” [8], and therefore the use of IT promotes a closer relationship between education and industry.

The case of the Michelson interferometer presented here combines the technology of virtual and remote laboratories, while permitting students to interact with each other and their teachers via a Moodle platform and face-to-face interactions in class. This is therefore a complex pedagogical tool with a potential for learning that results from the combination of technology and personal relationships.

There has been some discussion over the relative advantages of real, virtual and remote laboratories in education (see [8] for a review). The advantages of real labs relate both to the opportunity students have to experience real data and to face real-life problems and unpredicted errors, but are recognized as too costly and not necessarily inspiring for students. Virtual labs give students the opportunity to understand and explore fundamental concepts as they can “visualize and interact with dynamic processes” [1], but are accused of being disconnected from reality and not enabling learning by trial and error. Remote labs have the benefits of flexibility and presentation of real data, but their realism for students is sometimes questioned. As a result, real, virtual and remote labs are recognized as having both potentials and limitations in terms of students’ learning – but IT devices are frequently criticized for their inability to allow a genuine “hands-on approach" and for promoting what we could designate as a *Lucky Luke syndrome* or, following Kester et al. [9], a tendency to encourage "lone learners".

The description above clearly illustrates the typical learning advantages (and disadvantages) of remote and virtual labs, beyond the obvious benefits in terms of time and geographical flexibility and cost-effectiveness: the opportunity to construct a deeper understanding of basic concepts, the direct experience of the technology involved in designing remote and virtual environments, the possibility to work at one's own pace and to experience higher levels of self-directedness, autonomy and responsibility towards personal learning.

Additionally, the combination of this learning object with a Moodle platform that enables students and teachers to interact in both synchronous and asynchronous forums helps overcome a fundamental critique regarding learning in virtual and remote labs: the non-existing or limited opportunities for student-to-student or student-to-teacher dialogue and discussion [10, 11]. In fact, as participation in learning communities and authentic tasks is increasingly recognised as essential for learning, so is the social context and the interpersonal synergies generated in these communities – either real or on-line [12, 13].

Obviously, the next step is to design a systematic evaluation project of the learning processes and of the learning effectiveness of this promising combination of IT tools on students' understanding and competencies related to the use of the Michelson interferometer.

## V. FINAL REMARKS

This paper presents a learning object built around a Michelson interferometer. This learning object has several components including a remote laboratory, a virtual laboratory and a set of online seminars and other tutorial materials. All components are integrated in a Moodle platform enabling students to interact with each other and their teachers on and offline, creating a learning community around a well focused and real task: the measurement of displacement with high resolution. This learning object can be accessed at http://foton.fe.up.pt/moodle/course/view.php?id=20.

As the presented object is less than one year old it is still too soon to comment on its effectiveness as a learning tool. A systematic evaluation of its contribution for the learning process is under development.

The contents will soon be available in English. The remote control of the sliding mirror of the interferometer set-up will be further improved.

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## REFERENCES

[1] R.A. Serway, J. S. Faughn, C. Vuille and C. H. Bennet, "College Physics", Thomson Brooks/Cole, pp. 836-837, 2005.

[2] Length and related quantities capabilities, National Measurement Institute, Australia, http://www.measurement.gov.au/, (2007).

[3] Displacement Transducer Calibration, the UK's National Measurement Laboratory,NPL, http://www.npl.co.uk/length/dmet/services/ms_disp_trans.html, (2007).

[4] D. D. Teixeira, F. J. L. Pereira, J. F. B. Carvalho, S. M. B. Leitão, R. A. G. Bencatel, J. E. Villate, Maria T. Restivo, M. F. Chouzal and F. G. Almeida, A Michelson Interferometer For A Virtual Laboratory, Proceedings M2D'2006, 5th International Conference on Mechanics and Materials in Design, Edition INEGI, ISBN: 972-8826-10-9, Portugal, (2006).

[5] C. Huang, Virtual Labs: E-Learning for Tomorrow. PLoS Biol 2(6): e157 doi:10.1371/journal.pbio.0020157, 2004.

[6] S. Hrastinski, C Keller, Computer-mediated Communication in Education: A review of recent research, Educational Media International, Volume 44, Issue 1, pages 61 - 77 2007.

[7] C. Huang, Changing learning with new interactive and media-rich instruction environments: virtual labs case study report, Computerized Medical Imaging and Graphics, Volume 27,Issue 3, Page 157-164, 2003.

[8] J Ma, JV Nickerson , Hands-on, simulated, and remote laboratories: A comparative literature review, ACM Computing Surveys (CSUR), Volume 38 , Issue 3, pp. 1-10, 2006.

[9] L. Kester, P. van Rosmalen, P. Sloep, F. Brouns, M. Brouwers, and R. Koper, Matchmaking in Learning Networks: A System to Support Knowledge Sharing. Proceedings of International Workshop in Learning Networks for Lifelong Competence Development, TENCompetence Conference. March 30th-31st, Sofia, Bulgaria: TENCompetence. Retrieved June 30th, 2006, from http://dspace.learningnetworks.org.

[10] VP Dennen, TM Paulus, Researching" collaborative knowledge building" in formal distance learning environments, Proceedings of th 2005 conference on Computer support for collaborative learning: learning 2005: the next 10 years!, pages 96 – 104, Taipei, Taiwan, 2005.

[11] P. van Rosmalen, P. Sloep, F. Brouns, L. Kester, M. Koné and Rob Koper., Knowledge matchmaking in Learning Networks: Alleviating the tutor load by mutually connecting Learning Network user, British Journal of Educational Technology, Vol 37 No , pp. 881-895, 2006.

[12] J Herrington, R Oliver, and TC Reeves, Patterns of engagement in authentic online learning environments, Australian Journal of Educational Technology, 2003.

[13] J. Herrington, T C Reeve, and R Oliver Authentic tasks online: A synergy among learner, task, and technology, Distance Education, Volume 27, Issue 2, pages 233 – 247, 2006.

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