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Physics Experiments with Arduino and Smartphones

Springer

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Preface

I have been dreaming about writing this textbook for years. Finally, in late 2019, before the COVID-19 pandemic exploded, I met a far-sighted publisher who agreed to print it. I wrote three chapters of this book while Italy was in lockdown and courses at our University had been switched to remote learning, to the obvious detriment of laboratory courses. I was then asked to provide some help as to how these remote courses might be carried out and I came up with a few ideas that were met with scepticism at the beginning but indeed, resulted in complete success. Students were, in fact, learning even more than they might have with traditional courses. The reason, in my opinion, is simple: conducting experiments by yourself (by which I mean assembling all that is needed to perform the experiment, organising data collection and analysing the results through the creation of your own code) teaches a student much much more than they are likely to learn simply by pushing buttons to start an automatic device prepared by a teacher. Moreover, classical physics laboratory courses suffer from the misguided notion that the purpose of the experiments to be proposed to students is to see how closely they can follow the lecture material and imitate original equipment in their own constructions, thus making experiments look quite old-fashioned.

On the contrary, the purpose of laboratory courses should be to teach students how to design and conduct an experiment, interpret data and derive models. These skills must be developed using modern tools, in both hardware and software domains, such that students are prepared for practice in modern physics laboratories.

The idea behind this textbook is that laboratory practice is learnt by doing and is much less formal than theoretical physics courses. Often, the emphasis in these courses is on statistics, and they are full of mathematics that seldom catches the attention of students devoted to experimental physics. The main goal of the proposed experiments is to prove that a physical law is correct, but given that most of the physical laws can be formulated within a framework in which many approximations are done implicitly, this goal is rarely achieved. As a result, students get frustrated and lose confidence in their experimental abilities. Finally, in many cases, operations are tedious (repeat the same measurement many times over, compute complicated derivatives and solve difficult equations or systems of equations, etc.), without even the benefit of being useful for the development of the competencies. None of us compute averages or uncertainties about measurements using the techniques adopted in university courses. We rather use automatic computation, having learnt a programming language. That's why computer programming is taught in physics courses. However, too often, computers are not used in laboratory courses to derive results, in the mistaken belief that doing math manually is the only way to learn and that writing computer programs is a waste of time.

My textbook is thus organised such that the knowledge is acquired progressively, increasing from chapter to chapter, sometimes overriding (or, more accurately updating) the knowledge acquired up to a given point. Different topics (experiment design, data acquisition, statistical data analysis and their interpretation) are not discussed in dedicated chapters but are mixed in with an introduction to a modern programming language such as Python and complemented by a relatively detailed description of Arduino programming.

Sections are organised such that students (and teachers) less interested in programming can easily skip them to no detrimental effect or, at most, read them superficially. There is no need to conduct the experiments exactly as proposed: the descriptions are intended to be suggestions from which the reader can draw inspiration for his/her own design. Also, the suggested experiments are just examples that any teacher can use to then propose his/her own. The organisation of the volume is such that a teacher is also free to organise his/her own course in the way he/she prefers. Even the order in which the topics are presented does not need to be strictly followed, even if chapters are necessarily organised such that the initial ones present very basic data analysis that is progressively refined.

Primary ideas and important results are highlighted as side notes. All the content of the side notes is then summarised at the end of each chapter.

One final remark point: my personal belief is that laboratory courses do not necessarily have to follow theoretical courses. In fact, physics is done the opposite way: investigate new and unknown phenomena experimentally, formulate models and test them. As a consequence, it is perfectly viable (indeed, in my opinion, sometimes preferable) to perform experiments on topics not yet mastered by students. However, most physics courses are organised differently, and we agreed that it was a bit audacious to propose a radically different textbook. For this reason, the experiments proposed have to do with mechanics, traditionally the first topic taught in physics courses. There is no need to perform the exact same experiments. Many variants can be imagined and possible alternatives are proposed on the book's website.

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This book would probably never have been written if it had not been for Morten Hjorth–Jensen, from the University of Oslo, who urged me to write it in recognition of its potential. The idea was born during a short stay in Oslo, where I went thanks to a very kind and useful invitation from Morten, whom I want to warmly thank for the opportunity he gave me to visit his wonderful country and to collaborate with a team of researchers and teachers open to innovation and didactic experimentation. I hope to repeat this experience. I also want to thank Marina Forlizzi, who believed in this project and promoted it at Springer.

I also want to thank Julien Bobroff and Frédéric Bouquet, from Université Paris–Saclay, whom I had the good fortune to meet a few years ago, almost by chance, and with whom I share a vision of the importance of conveying science through new languages, including art. It was a great pleasure to work with them and their collaborators, too.

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Last, but not least, I thank Federica for her patience and support. I recognise that, sometimes, it can be difficult to be my wife, but I will be forever grateful to her for that.

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