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Practical courses without presence - is that possible?

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Abstract

Praktika stellen eine zentrale Komponente der ingenieurwissenschaftlichen Ausbildung dar. Im Rahmen von Präsenz-Veranstaltungen werden derartige Praktika in Vorlesungen mit großen Hörerzahlen in der Regel in dicht besetzten Praktikumsräumen mit Gruppen von deutlich über 10 Studierenden durchgeführt, um überhaupt die Verteilung der Praktikumsversuche über das Semester gewährleisten zu können. Unter Pandemie-Bedingungen waren diese Präsenzpraktika nicht mehr durchführbar, wodurch entweder die Möglichkeit bestand, (i) die Praktika ausfallen zu lassen, (ii) sie als Computer- oder Vorführversuche im Videostream zu gestalten oder (iii) neue Konzepte zu suchen, mit denen reales Experimentieren zu Hause möglich werden kann. Da der Ausfall zu signifikanten Störungen des Studienablaufs geführt hätte und reine Computerversuche einer experimentellen Ausbildung geschadet hätten, wurde am Lehrstuhl f. Magnetofluiddynamik, Mess- und Automatisierungstechnik der TU Dresden eine Praktikum@home–Struktur entwickelt, die sowohl die erforderlichen Lehrinhalte transportiert als auch experimentelles Arbeiten ermöglicht. Die entwickelten Konzepte und die damit gemachten Erfahrungen sind Gegenstand dieses Beitrags.

Practical courses are a central component of engineering education. In the context of face-to-face courses, such practicals in lectures with large numbers of students are usually carried out in densely occupied practical rooms with groups of well over 10 students, in order to be able to guarantee the distribution of the practicals over the semester at all. Under pandemic conditions, these face-to-face practicals were no longer feasible, which meant that there was either the possibility of (i) cancelling the practicals, (ii) designing them as computer or demonstration experiments in a video stream, or (iii) looking for new concepts with which real experimentation at home could become possible. Since the failure would have led to significant disruptions in the course of studies and pure computer experiments would have been detrimental to experimental training, a Praktikum@home structure was developed at the Chair of Magnetofluiddynamics, Measuring and Automation Technology at the TU Dresden, which both transports the required teaching content and enables experimental work. The concepts developed and the experiences made with them are the subject of this article.

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1. Practical courses in the context of the overall teaching concept

Practical courses are a central component of the education, especially in engineering studies, but also in many natural science courses. By working on real existing plants, they create a link between the often very theoretical lecture content and the real working and living conditions. At the same time, the number of practical courses offered in engineering degree programmes is constantly decreasing, especially in the basic subjects with large numbers of students, due to the immense demands on personnel, time and space.

When considering practical courses - especially considering the Corona pandemic situation, which has massively impaired teaching activities at universities since the summer semester 2020 - a fundamental distinction must be made between practical courses within the framework of special lectures and those within the framework of basic lectures. Practical courses for special lectures with low numbers of up to 50 students can also be carried out in presence, even with contact restrictions with increased personnel and time expenditure.

In contrast, this possibility is actually excluded from the outset in the case of practical courses for basic lectures with several hundred listeners. Nevertheless, in these subjects in particular, the practicals are an essential component that, in addition to subject knowledge, must also provide enthusiasm for the subject in question and thus the motivation to deal intensively with the content. Under the conditions of the pandemic and lockdown, the motivation aspect was already a very important aspect in the summer semester of 2020, and its significance continues to grow with the increasing duration of the restrictions in academic teaching.

In all considerations regarding the implementation of practical courses in the pandemic situation, it also always had to be taken into account that it is not possible to cancel practical courses that are anchored in the curriculum and that postponing them to later semesters would lead to extreme additional burdens on the students.

2. The course

The course, Measuring and Automation Technology (MAT) is a two-semester module starting in the winter semester. It consists of 2 SWS lecture, 1 SWS exercise and 1 SWS practical course.

The course was held in the summer term 2020 with 450 participants. From the winter semester 2020/21 onwards, there will be approx. 600 students per semester due to a change in the study and examination regulations.

Under the conditions of the Corona pandemic, the lecture was made available as a YouTube livestream [1], as other streaming structures did not have the necessary stability for the large number of listeners, and at the same time only a live event allows interaction, albeit limited, between students and lecturers. In addition, livestreaming on YouTube offers the advantage that an asynchronous form of the course is available directly after the event, which was indispensable under the conditions of the lockdown. In addition, the recordings on YouTube can be implemented comparatively well in terms of data protection law, as no conclusions can be drawn about the students present due to the fading out of the live chat, via which interaction with the students takes place during the lecture.

Matrix rooms and in individual cases ZOOM meetings were used for the exercises.

The biggest problem for the implementation of the course is obviously the practicals. In terms of the concept, the course is designed in such a way that three experiments are carried out in attendance per semester.

In the summer semester 2020, the advantage was that the students had already participated in the first group of events on measuring and automation technology in the winter semester and were therefore familiar with the teaching concept and the people involved. This advantage ceased to exist with the winter term 2020/21, because a new cohort started the module here.

The semester ends with a written examination, which has been conducted in digital form via the BPS OpalExam online examination tool since the summer term 2020. Experiences with the creation and implementation of the online exams are reported elsewhere [2].

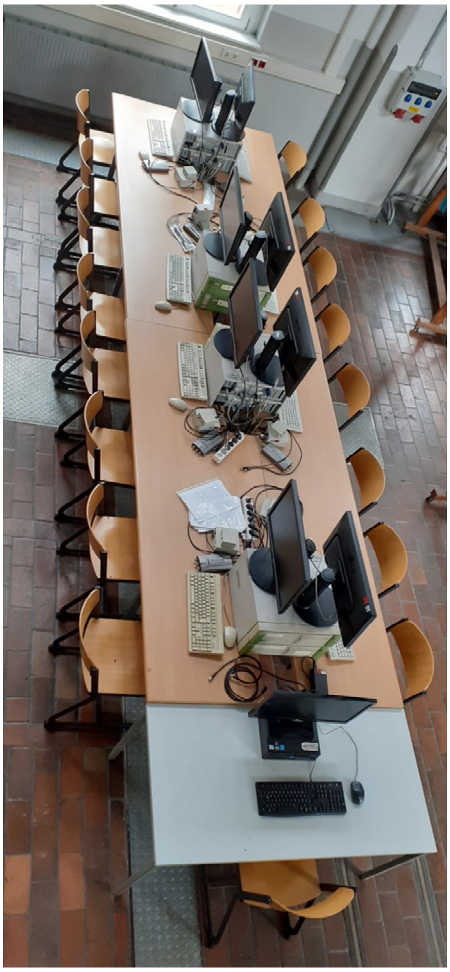

Fig. 1: Typical arrangement for a classroom practical (here measurement dynamics) for 16 participants and one supervisor.

In normal attendance semesters, the practical experiments are implemented in groups of 16 students, who carry out the practical in groups of two at eight experimental stations with a supervisor. The practical experiments are accommodated in areas of the order of 25 m² for the corresponding 16 participants and the associated supervisor (see Fig. 1). If one takes the spacing rules into account that the university management has set since the summer semester 2020, at least up to and including the summer semester 2021, this means that practicals could be carried out with three, at most four participants, depending on the spatial arrangement. With a total number of around 110 practical course units that have to be carried out per semester for 600 students in a year group, this represents an enormous additional burden in terms of personnel and spatial resources. This results in up to five times the amount of supervision required.

This meant that a comprehensive redesign of the practical course operation had to be carried out as early as the 2020 summer semester, which then had to be significantly expanded - with a view to the completely digital 2020/2021 academic year.

With a view to a later comparison between face-to-face practicals and practicals with a high proportion of digital components, it is also worth pointing out at this point the quite well-known problems in face-to-face practicals. First and foremost, this includes the fact that only a very limited amount of classroom time is available. In this short time, the students have to familiarise themselves with the practical, carry out the individual experiments and evaluate them. Since the preparation is usually done via written practical course instructions, this leads to the fact that the effective learning success of such practical courses hardly justifies the technical and personnel effort that is associated with the preparation and implementation of the practical courses. Only those students who have prepared for the practical course with a correspondingly high level of effort will gain a real benefit in terms of content from carrying out the practical course. This has been a problem within the framework of the implementation of the practical courses for many years, which we have dealt with, but for which we have not been able to find a solution, because the motivation of the students to study on their own is often very low.

3. Initial situation in the summer semester 2020

Due to the Corona crisis and the lockdown associated with it, it was not clear for a long time in spring 2020 whether and to what extent face-to-face teaching would be possible. For the practical course in MAT, this meant that as time went on, the time window available for carrying out the practical experiments became smaller and smaller, so that even before the decisions of the university management on the implementation of face-to-face teaching, it was clear that even with normal full occupancy of the practical course rooms, it would no longer be possible for all students to carry out the experiments purely in terms of time.

Since MAT is a two-semester module starting in the winter semester, the students who were registered for the course in the summer semester had already carried out three experiments in presence in the winter semester. This automatically reduced the selection of experiments that could be used for a digital practical and adapted to the material of the course.

As a rule, i.e. in semesters with classroom teaching, three practicals are scheduled for the summer term:

One experiment on **measurement dynamics**, one on the **control loop** and a third on the **programmable logic controller (PLC).**

The experiment **Measurement Dynamics** deals with the influence of signals by transmission elements with time delay as well as with the conversion of analogue signals in digital measurement systems. Questions of the true-to-shape reproduction of signals are to be experienced in practice as well as the effect of the sampling theorem on digitally recorded signals. The experiment for the classroom teaching consists of a function generator, electronics that represents the time-dependent behaviour of the transmission element, and an oscilloscope card in a computer that records the input and output signal and makes it available for evaluation via corresponding software.

The experiment **Control loop** consists of an elevated tank that is filled with water via a submersible pump. The pump is to be controlled via an external electronic controller in such a way that the water level, which is determined via a pressure sensor at the bottom of the elevated tank, can be maintained at a given setpoint. The task is to characterise the controller and the track and to practically implement the control task as such.

The **PLC experiment** is by far one of the most popular experiments in the MAT practical course, as a large railway system equipped with many points, reed switches to determine the position of the train and controllable transformers to set the speed has to be programmed for certain driving tasks with the help of a Siemens PLC. For this purpose, the students create the programmes for the PLC on available computers, which are then uploaded to the PLC during the evaluation of the experiment with the supervisor of the practical course, whereupon the movement of the train on the layout can be observed, which makes possible errors directly visible.

4. The situation for the winter semester 2020/21

In the winter term 2020/21, it was again not possible to conduct classroom practicals, as the number of students had risen to 600 in the winter term and the spatial restrictions, together with the spacing rules, the available practical time and the available staff, made it impossible to conduct classroom practicals.

Since a fundamental reorganisation of the lecture was necessary anyway due to the shortening of the semester by two weeks, this reorganisation was realised specifically with a view to the practical course. Two experiments that had been made available as home practicals in the summer term were taken over into the winter term. The home experiment on digital image processing and the computer experiment on measurement dynamics could be integrated well into the course of the lecture in terms of content and topic, and by structuring the lecture accordingly, it was possible to ensure that, in contrast to the usual classroom practicals, the necessary lecture material had been taught before the practicals were carried out.

The third experiment in the programme is a new home experiment for **planning experiments and calculating errors.** This involves the fundamentally simple problem of determining the acceleration due to gravity from the period of oscillation of a pendulum, which is already familiar from the physics practical course at the beginning of the degree course. In principle, this is a simple experiment in terms of the theory behind it, but the tricky part lies in the details when it comes to setting it up and carrying it out.

5. Implementation possibilities within the framework of digital semesters

Two basic preconditions were set for the implementation of the experiments as a presence-free practical course: On the one hand, a purely digital practical course was not to be created under any circumstances, as experimentation is and must be a significant component of practical training. The second precondition was aimed from the outset at combating the expected loss of motivation among students in an online semester and with massively reduced contact opportunities. In a nutshell, this meant that the practical course had to be fun!

The lab course **measurement dynamics** can obviously be implemented digitally without any serious compromises. For this purpose, a programme had to be developed that allows a time-dependent input signal to be generated, modified via the known response functions of time-dependent transmission elements and output in a graph (Fig.2). The programme was developed using Python and the students were provided with an executable file depending on the operating system, which generates a "laboratory number" when started, which means that all students have different parameters set in the software, which means that the results cannot simply be taken over by fellow students.

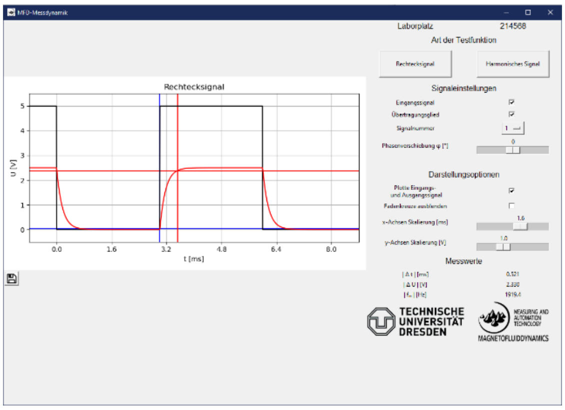

Fig. 2: Software interface of the measurement dynamics experiment with input and output signal and measurement data display.

In theory, such a programmatic solution is easy to implement. However, it must be taken into account that the realisation of a software that runs stable on a wide variety of operating systems can be an extraordinarily complex challenge. Programming and testing the practical programme under Windows, Linux and IOS are tasks that required an extraordinary amount of time, so that this experiment could only be used at the very end of the summer term.

The **control loop** experiment, which already causes the students the greatest problems in the classroom practical, could in principle also be implemented with a programming solution. However, the programming proved to be too complex for the time available, so that this experiment had to be abandoned in the summer term 2020.

Fig. 3: Camera view of the railway system in the PLC experiment to observe the train movement.

The **PLC** experiment, on the other hand, can be implemented relatively well in a digital version, since the students can also create the corresponding programme on their own computers. The necessity is also given by the fact that the licensed development environment for the PLC cannot be made available to the students to such an extent.

In order to enable the automatic insertion of variable names into the programme code, which is typical for the Siemens Step7 development environment, the freeware text editor Atom was used, in which a text file with the variable names can be integrated, whereupon these are available as auto-completion. The challenge was then to make the moving railway visible to the students, thus retaining an essential motivational aspect. For this purpose, multiple cameras were mounted on the railway system, which could be used to observe the movement of the train during a GoToMeeting session (Fig. 3).

Thus, one experiment was missing for the complete implementation of the practical course in the summer term. For this purpose, a topic from the MAT1 lecture - the characterisation of a camera with regard to its resolution, i.e. the determination of the modulation transfer function - was used, which could be implemented as a real home experiment. This experiment (**digital image processing**) can be carried out with any camera without impairing the learning effect. This ensures from the outset that every student can carry out the experiment. Regardless of whether the camera of the mobile phone, a tablet or laptop, a webcam or an elaborate SLR camera is used - the experimental steps are the same. The questions of interpreting the result can also be dealt with in an identical way. The only additional component required is a razor blade or, if one is not available, a straight edge such as is typically found on a kitchen knife. With this, a real experimental home test can be carried out.

The additional experiment **design and error calculation** developed for the winter semester requires an extremely detailed experiment design for a precise determination of the acceleration due to gravity.

This can easily be seen in an example that was carried out with considerable effort at the Chair of Magnetofluiddynamics Measuring and Automation Technology.

A large mathematical pendulum with a pendulum length of 11.83 m was installed in the stairwell of the Mollier Building (Fig. 4), the period of oscillation was determined using digital image processing and all the essential and recognisable requirements for using the theory for a mathematical pendulum were met.

Fig. 4: Experimental set-up "Pendulum" in the stairwell of the Mollier Building

In particular, a pendulum cord made of dental floss was used, whose mass was negligible compared to the mass of the pendulum bob. The evaluation of this experiment resulted in a gravitational acceleration of (9.818+0.012) m/s2 and thus a deviation of 0.06 % from the value [8] of 9.81168 m/s2 given by the Physikalisch Technische Bundesanstalt (PTB) for Dresden. We will return to this deviation later.

In total, a good 500 values for the acceleration due to gravity were determined in the practical course. Fig. 5 shows the distribution of values obtained. The mean value is (9.81085+0.0068) m/s2 (the fact that more digits are given here than is usual for the given error is due to the comparison with the PTB value) and thus deviates only 0.008% from the value given by the PTB.

The fact that this deviation is significantly smaller than that of the aforementioned pendulum experiment in the Mollier Building is due to the fact that the dental floss used as the

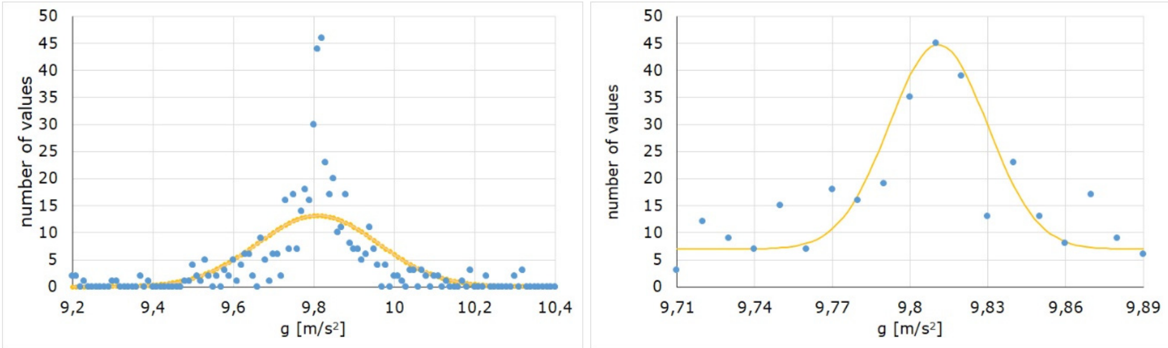

Fig. 5: (a) Overall distribution of the data obtained in the practical course and (b) Gaussian distributed data around the expected value.

pendulum cable is slightly flexible. This stretching causes a change in the length of the pendulum at the reversal points, which in turn leads to deviations in the period of oscillation, which in turn give rise to an, albeit small, incorrect determination of the acceleration due to gravity.

This example shows that the experimental design is of central importance for the measurement result at this point.

The finding that there is a deviation from the normal Gaussian distribution in the distribution shown in Fig. 5a is due to the fact that we are looking at the overall distribution here. If we only look at the data in Fig. 5b that are close to the expected value for the acceleration due to gravity, i.e. those that only deviate from this value due to random errors, we see an excellent Gaussian distribution for a total of a good 320 values. Through the debriefing of the experiment with the students in the lecture, the fact that randomly erroneous measured values are Gaussian distributed could thus be proven with a practical example far beyond the normal theoretical discussion of this lecture content and thus strengthened the further understanding of the students.

6. Overall implementation

For the overall implementation of the digital practical, the practical manuals first had to be converted to the modified experiments for home use.

As a substitute for the introduction to the practical course typically provided by the practical course supervisor, introductory videos were created for each experiment in which all steps of the practical course were explained in detail with concrete instructions for implementation [4-7]. These videos, like the lecture videos, were made available on YouTube.

The practical instructions, the programmes required for the experiments measurement dynamics and PLC as well as a sample protocol were made available on the Opal learning platform in the respective MAT courses.

From the start, each experiment had three weeks to complete. After approx. 1-1.5 weeks, chat rooms for real-time communication were opened for groups of approx. 60 students, in which questions about the experiment could be asked in consultations. These rooms can be created at the TU Dresden using the ***Matrix*** tool [9], after which a further 1.5-2 weeks were available for final processing.

The resulting protocols of the practical experiments had to be uploaded by the students in the Opal course in folders sorted by field of study.

In the introductory videos, it was explicitly pointed out that it makes sense to work together in groups during the practical course. Even though these groups could essentially only confer digitally due to the contact restrictions in both the summer and winter terms, it could be determined that the students had actually specifically come together in groups to work on the corresponding experiments.

It was not possible for the students to download the protocols, so that no unauthorised exchange of protocols could take place.

After uploading the protocols, the evaluationand awarding of grades could take place comparatively quickly, as the questions in the sample protocols had to be answered specifically and then points could be awarded accordingly, which could be registered via an Excel sheet and converted into the practical course grades. The standard grading system for measuring automation technology was used to calculate the marks.

7. Experience with the digital practical courses

The first experience with the digital practical course was that we noticed a quasi 100% participation of the students in the experiments.

Furthermore, it could be seen that the students came to the consultations in the matrix rooms extraordinarily well prepared. It became apparent that after the 1-1.5 weeks that were available until the consultations, they had already worked intensively on the experiments, so that questions could be asked in a very targeted manner. This extremely positive trend continued in the examination of the results of the practical tests. It became apparent that the performance achieved to a considerable extent went far beyond the required tasks.

To give two examples: In the summer term, in the experiment for the characterisation of digital cameras, the creation of two modulation transfer functions and their comparison was required. In very few protocols, only two corresponding modulation transfer functions had been recorded. Most students had changed a large number of parameters, determined the corresponding modulation transfer functions and subsequently written down extremely extensive discussions of the results. These evaluations often showed a profound understanding of the corresponding task and its core problems.

In the winter semester, a similar trend was seen, for example, in the experiment to determine the acceleration due to gravity. Here it could be observed that the students had planned and set up this experiment with considerable effort in some cases. Measuring systems with light barriers and Arduino controllers, measurements using digital image processing, complex determinations of the moments of inertia of the pendulum masses and the like were found in hundreds of protocols.

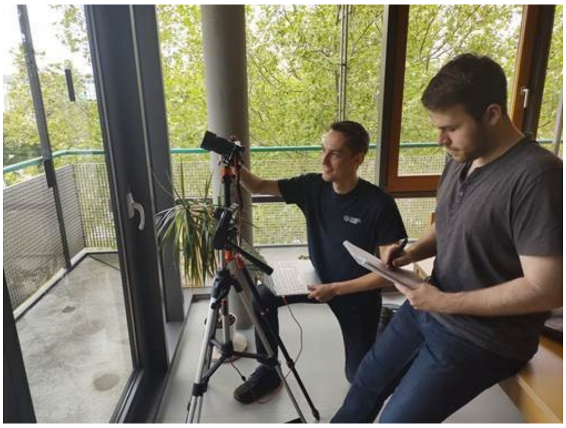

Fig. 4: 2 students in an empty dormitory performing the camera characterisation experiment. [10]

Thus, the learning effect in this practical course appears to have been significantly higher than in the previous classroom practical courses. On the one hand, this is probably due to the fact that the students had the opportunity to work on the problem over a longer period of three weeks, were able to exchange ideas with their fellow students and therefore went into the consultations well prepared. On the other hand, this form of practical course obviously offered a welcome change in the very difficult situation of the digital semester, which was able to interrupt the daily routine, which was partly demotivating and frustrating due to the lockdown, with concrete practical work.

8. Outlook for the summer semester 2021

Since, as mentioned, MAT is a two-term course, the experiments that were used in the summer semester 2020 cannot simply be used again in the summer semester 2021, since the computer experiment on measurement dynamics and the home experiment on digital image processing were already used in the winter semester. The experiment on PLC will remain for the summer semester.

Thus, two experiments are required to complete the overall curriculum of experimental training in MAT. In doing so, two decisive topic complexes from MAT are to be covered. On the one hand, the static and dynamic characterisation of measuring elements is missing with the experiments in the programme so far, and on the other hand, the subject area of control loops is also to be implemented experimentally in the summer semester.

While the characterisation of transmission elements can only be carried out in real experiments, in principle experiments on the control loop could be made available as a computer programme analogous to the experiment on measurement dynamics. However, this would mean that the students would no longer have to deal with the topic in concrete experiments.

For this reason, a new concept for home experiments, which can be expanded in the future, was installed for the summer semester with the support of the FOSTER programme of the TU Dresden [11]. These are experimental cases that are intended to enable real measurement and control experiments. I.e. these experimental cases are equipped with the sensors and actuators required for the experiments and also contain an Arduino microcontroller.

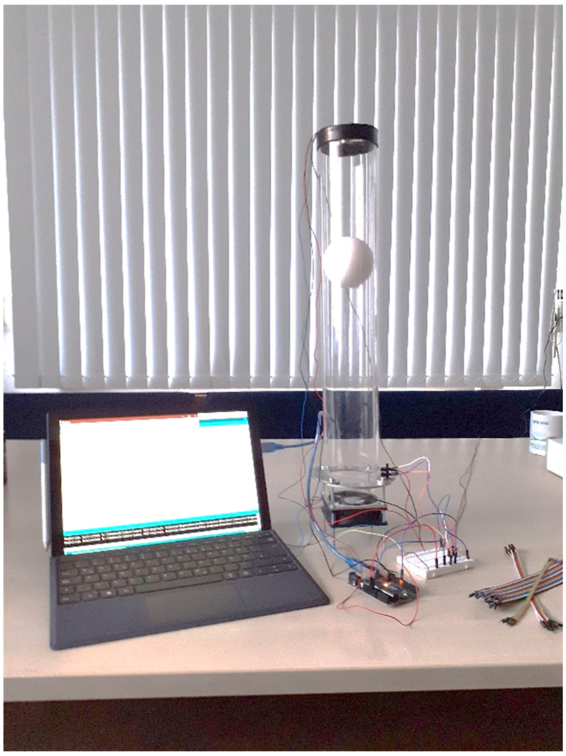

Fig. 6: Experimental set-up for the control loop with controlled system and metrological periphery.

With these experiments, two didactic aspects can be achieved. On the one hand, the normal practical tasks of MAT are implemented in real experiments to be set up by the students and, on the other hand, the students are familiarised with the use of microcontrollers using the example of the Arduino microcontroller.

From the didactic conception, the first experiment will include some experiments on the basic use of the Arduino and, on the other hand, will focus on the characterisation of a temperature sensor with regard to both its static and its dynamic properties. Apart from the components included in the experimental kit, the students actually only need a pot of boiling water and a computer from which they can control the Arduino for this experiment.

The second experiment on the control loop will address the most varied aspects of control technology using a very illustrative example of position control of a polystyrene ball (Fig. 6) in a Plexiglas tube.

For both experiments, students are provided with basic programmes for the Arduino. This is done because students who have not worked with Arduino up to this point would otherwise face the problem of first having to familiarise themselves completely with the use and programming of the Arduino. At the same time, however, students are offered the opportunity to modify these programmes and optimise them if necessary. In the latter case, the corresponding codes must be included in the protocol for the subsequent evaluation of the measurement results.

9. Lessons Learned

Previous experience with home experiments in MAT has shown that students take advantage of the opportunity to work with the experiments over several weeks to carry out extensive series of experiments and thus achieve a much deeper understanding of the content aspects. We attach great importance to the interpretation of the data and their critical reflection in the protocols of the experiments.

If one looks beyond the time of digital practicals, some changes immediately arise that can be made to a then hopefully possible presence practical. In experiments such as measurement dynamics or PLC, it is obvious that working on the practical tasks at home offers decisive advantages, as it provides more time and one can then use the time in the face-to-face consultations to clarify with the students the questions left open after working on them. In this way, both in these experiments and in the other experiments used in the MAT, it is hoped that the students' engagement with the practical material will be strengthened and thus their understanding of the relevant content will be significantly enhanced.

Acknowledgement

Many thanks go to the entire Magnetofluiddynamics team, who contributed to the success of the digital MAT practical course with ideas, help with the technical implementation, the development of the Arduino experiments, the revision of the practical course instructions and the testing of the experiments. Special thanks go to Mr. Höbold and Mr. Sturm for developing the experimental kits for the coming winter semester and Mr. Mokronowski for creating the introductory videos! Furthermore, we would like to thank the FOSTER programme of the TUD (Excellence Funding) for the financial support for the creation of the experimental kits, which will contribute significantly to the implementation of the future practical course structure.

Literature

[1] https://bit.ly/MFD-YouTube-Kanal
[2] E. Dohmen, A. Lange, B. Kraus, S. Sturm, S. Odenbach, Online-Prüfung mit OPAL, ONYX und MAXIMA Chancen und Grenzen, Lessons Learned (2021) 1,1/2 https://doi.org/10.25369/ll.v1i1/2.8
[3] https://de.wikipedia.org/wiki/Atom_(Texteditor)
[4] Versuch „Digitale Bildverarbeitung“: https://youtu.be/LHhgr0nVBQI
[5] Versuch „SPS“: https://youtu.be/59xzLzSklWw
[6] Versuch „Messdynamik“: https://youtu.be/m-v4U2nx25Q
[7] Versuch „Versuchsplanung und Fehlerrechnung“ https://youtu.be/GzEDpFrs7tU
[8] https://bit.ly/g-Extractor-PTB
[9] https://doc.matrix.tu-dresden.de/
[10] Foto: Julian Hagert, priv. comm.
[11] https://tud.link/6gws