Digital and Low-Cost – Development of a Polarimeter on a Raspberry Pi

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Abstract

Digital data acquisition in science lessons is a particular challenge in terms of availability and operation of the devices. Classical laboratory measuring instruments often focus on data acquisition, which is why the handling in the classroom varies greatly depending on the manufacturer and equipment. Access to complex measuring equipment such as spectrometers or polarimeters is further complicated by high costs. With the help of individual electronic components and various materials or in combination with a 3D printer, some of these measuring devices can be reproduced, which makes access in STEM-classes inexpensive [1-3]. At last, the measurement values are recorded by handwritten transmission and application of measured variables or the strength of acoustic signals, which on the one hand requires time and on the other hand can make joint evaluation difficult.

The LabPi software [4], which was specially developed for the Raspberry Pi single-board computer, offers an additional digital solution to this challenge. This software combines different measuring instruments to a uniform low-cost measuring station with the help of a multitude of miniature sensors. It is didactically tailored to teaching and thus offers a basis for supplementing previously analog processing steps with the aspect of digital data acquisition and evaluation.

The article presents the development of a low-cost polarimeter based on the Raspberry Pi and the software LabPi. The construction and the functionality of the digital polarimeter are described by means of simple components. In addition, the possibilities for digital evaluation and visualization of optically active substances are presented by means of selected comparative measurements.

Keywords: *Measurement Systems, LabPi, Digitalization, STEM Education 4.0*

1. Measured value acquisition in STEM lessons

Digital measuring systems have become indispensable in everyday life. Whether in industry or in the laboratory, measured variables such as temperatures, pH values, conductivities or concentrations can be recorded and evaluated quickly and, in some cases, fully automatically with the help of computer-aided measuring systems. Progressive digitization means that learners should be prepared for future challenges, but digital measurement acquisition in schools still represents a major challenge. The acquisition of digital measuring instruments such as spectrometers, gas chromatographs or polarimeters is often associated with high costs for schools. Once purchased, they are only available to teachers, which means that the devices are mainly used in demonstration experiments.

To enable students to use suitable measuring equipment, a whole range of low-cost measuring devices have been developed. These range from melodic conductivity testers to homemade LED photometers [1-3]. However, the evaluation is still often done by hand. A digital extension to this is offered by single-board computers such as the Raspberry Pi. Combined with appropriate sensors, the Raspberry Pi can serve as a basis for digital data acquisition and as a complete computer on which evaluation can be performed using suitable office applications.

In chemistry classes, polarimetry is integrated into the subject area of hydrocarbons, especially when the optical properties of sugars and chiralities are discussed. It is therefore all the more important that optical effects, such as the rotation of polarized light, can also be analyzed practically. This paper therefore presents the development and testing of a digital low-cost polarimeter based on the Raspberry Pi with its own software.

2. Development and the Software LabPi

Digital polarimeters are among the most expensive measuring instruments that can be used in educational institutions. Even the purchase of an analog measuring device can be in the high three-digit range. Even if the precision of the conventional measuring instruments is very high, the data acquisition is a big challenge. Reading of measurement data must be trained and are read differently by learners. Lastly, the comparability of data must be gathered from all learner groups if possible.
The digital polarimeter presented here should be able to be integrated with easily accessible components in the low-cost range. Furthermore, by building the device oneself, the functions of the individual components and their mesh are easier to comprehend, which can counteract the black box character for learners.
The angle of rotation is measured in a similar way to a photometer via the light intensity or the transmission of aqueous solutions. This is detected by a digital light sensor [4] using a yellow LED (570 nm) as the light source. Two polarization filters serve as polarizer and analyser, which can be purchased cheaply or taken from discarded 3D glasses. To be able to determine a rotation angle, the analyser was glued to a servo motor (Fig. 1).

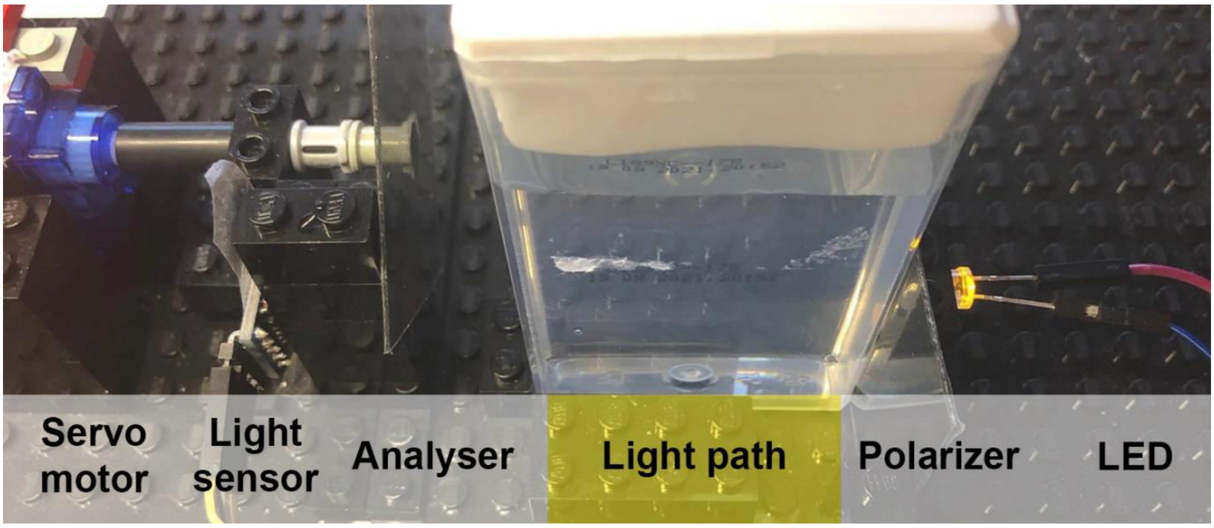
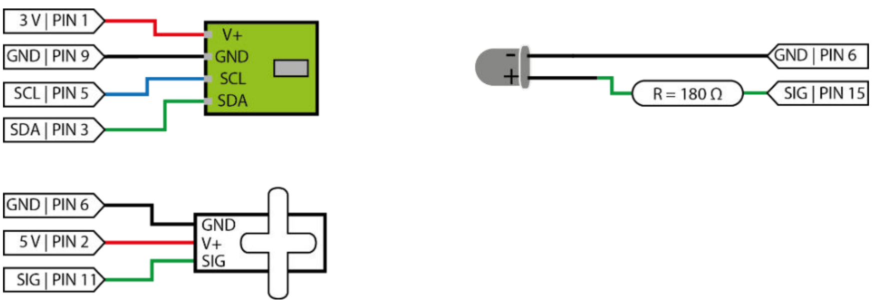


Fig. 1: The digital polarimeter buildup.

The structure is supported using various Lego bricks. These serve to stabilize the servo motor, but also as a socket for the LED, which is used to define the light path. The light intensity sensor is placed behind the analyser exactly opposite the LED.
For measuring aqueous solutions, a large, transparent plastic jar for peppermint candy is sufficient that a cuvette is not required. The inner diameter was determined in advance (d = 0.47 dm) and is necessary for the later experimental setup as a parameter of the layer thickness.
Figure 2 schematically summarizes how the electronic components are finally connected to the Raspberry Pi correctly. If the respective electronic components are connected as indicated and a suitable software operates the servo motor, it is possible to set a rotation angle from 0° to 180° and therefore to measure the respective light intensities.



Component	*Price*
Raspberry Pi	*40 €*
LED	*1 €*
Light sensor	*5 €*
Servo motor	*5 €*
Polarizer	*10 €*
Lego Bricks	*10 €*

Fig. 2: Schematic wiring of the of components on the Raspberry Pi's GPIOs and pricing of components.

To control the sensors of the digital polarimeter, the already existing software LabPi was used [5]. This software is freeware and allows the measurement with different sensors without programming skills. In addition, it has a user interface tailored to teaching, which was developed for the Raspberry Pi. The software was first adapted and expanded to the functionality of the digital polarimeter. LabPi thus takes over automated processes, such as moving the analyser and recording the measurement points. The software finally displays these in tabular and graphical form. The curve progressions and measurement data can then be compared directly in the software. Depending on the requirements of the learning group and the experimental setup, differences can be visualized and displayed on the graphical interface or the measurement data can be exported for further analysis (Fig. 3). In addition to recording and displaying measured variables, an upload function to the COMPare Cloud platform can be used, which opens collaborative learning opportunities and makes recorded graphs easier to compare. .

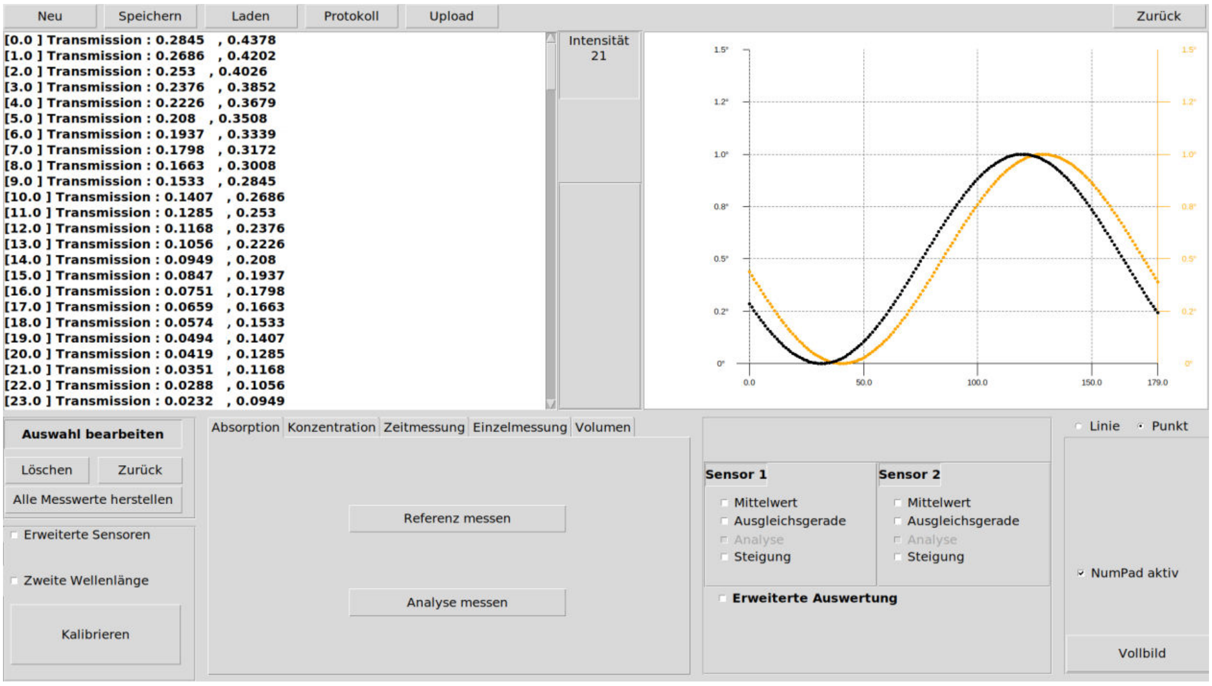


Fig. 3: Graphical User Interface of LabPi (in development) with measured water (black) and sucrose solution (0,3 g/ml).

3. Measurement and comparison

The angle of rotation is determined by rotating the analyser and recording the intensity values. The measuring points are recorded by LabPi and reproduced as transmission. This allows a complete sinusoid to be mapped when the analyser is rotated by 180°. The minimum and the maximum of this curve represent the measuring points for determining the change in the angle of rotation. These extremes, which are uniform in amplitude due to transmission, also help in the visualization of different sugar solutions. Depending on the concentration of the sugar solution and the layer thickness of the cuvette, the phase of the sinusoidal curve is thus shifted. The difference between the extreme points of the solutions to be measured allow the rotation of the polarized light to be determined (Fig. 4). To calibrate the digital polarimeter, the zero point was determined with distilled water.

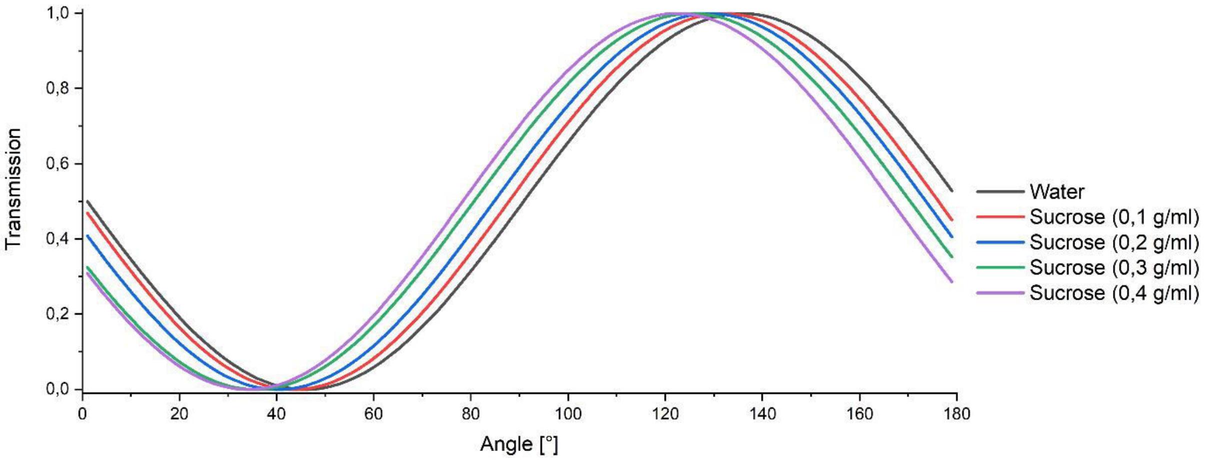


Fig. 4: Transmission of water and different sucrose solution by angle recorded with LabPi.

To determine the precision of the digital low-cost polarimeter, the specific rotation angle of sucrose was determined via a concentration series. In parallel, the solutions were measured with a conventional, analog laboratory polarimeter by Krüss Optronic [6].

Table 1: Measurement results and comparison between the digital LabPi polarimeter and an analog polarimeter.

Sucrose solution	*LabPi*	*Specific rotation*	*Deviation*	*Analog*	*Specific rotation*	*Deviation*
0.1 g/ml	*3 °*	*63.8 °*	*-3.87 %*	*12.65 °*	*63.3 °*	*-4.74 %*
0.2 g/ml	*6.5 °*	*69.1 °*	*4.14 %*	*27.75 °*	*64.4 °*	*-3.05 %*
0.3 g/ml	*10 °*	*70.9 °*	*6.81 %*	*38.65 °*	*64.4 °*	*-2.99 %*
0.4 g/ml	*13 °*	*69.1 °*	*4.14 %*	*52.40 °*	*65.5 °*	*-1.36 %*
Ø	*-*	*68.3 °*	*2.81 %*	*-*	*64.39 °*	*-3.03 %*

The table shows the calculated specific rotation angles in comparison. The deviations are related to the literature value of sucrose (α = 66.47°) [7]. The angles recorded with the analog polarimeter appear about four times as large as those of the digital polarimeter. This is primarily related to the choice of slice thickness, which corresponded to 2 dm for the standard cuvette and 0.47 dm for the plastic can. This difference is also one of the factors for the deviations from the literature value. The layer thickness also means that lower concentrations cannot be detected and are subject to greater error. Another point, which can enable a higher precision of the digital polarimeter, is the choice of the servo motor. The servo motor used here can align in 0.5° steps. Smaller steps can cause the motor to jitter severely, creating a much higher source of error for very small concentrations. Overall, the precision of the homemade polarimeter can be assumed to be sufficient for subject teaching and as a proof of concept.

4. Outlook

Both the polarimeter and the LabPi software are still under development. Especially for the polarimeter, further adaptations of the software are planned. At the current state, the determination of the specific angle of rotation is still dependent on office applications. In the future, this shall also be done via the software LabPi, whereby the results can be switched on optionally with only a few steps. In the future, it will also be possible to perform time-dependent measurements and concentration determinations with the aid of adjustable parameters. At the hardware level, further adjustments will be made to enable even more precise measurements before piloting with learning groups.

5. References

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