Rolling Sounds

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<Info>

<Keywords> fundamental science, data acquisition, circular motion, sound waves, geometry, trigonometry

<Disciplines> physics, mathematics, computer science

<Age level of the students> 14−17

<Hardware> Arduino microcontroller[1] or similar (with the appropriate drivers installed), microphone, high output buzzer, power drill with its base, materials for wooden disk setup

<Language> Snap4Arduino[2]

<Programming level> medium

<Summary>

This interdisciplinary educational scenario combines physics with computer science. It can either be used in a computer science class or in a physics class and it involves—along with the calculation of other physical quantities of uniform circular motion—the calculation of the linear velocity of rotation in two different methods.

The first of these methods detects how often the signal of an infrared proximity sensor is blocked by a small metal strip that is attached to a particular point of a rotating disc, thus measuring the period. The second method exploits the Doppler shift of a sound-emitting source placed on top of the disc.
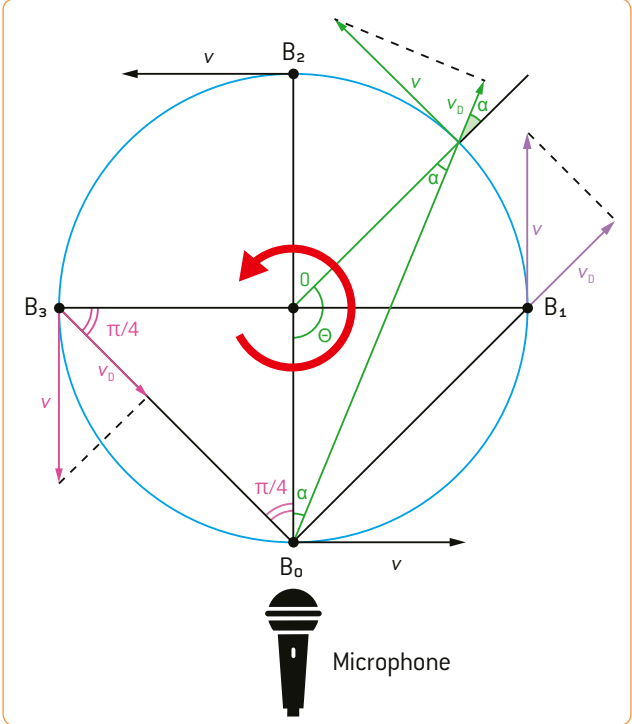
<Conceptual introduction>

The experimental study of the physical quantities (period T, frequency f, linear velocity v and angular velocity ω) of uniform circular motion is based on the knowledge acquired in Greek senior secondary schools (students' age: 14−17) and in the curricula of other European secondary schools. This also involves learning about the Doppler effect. The frequency and the magnitudes of angular and linear velocity are obtained by using well-known formulas:

$$f = \frac{1}{T}, \omega = \frac{2\pi}{T} \text{ and } v = \frac{2\pi r}{T}$$

T is derived from the microprocessor's internal clock, i.e. the time between signal detections, and radius r stands for the distance between the metal strip, or the buzzer, and the centre of the disc.

<Doppler effect experiment>

The Doppler effect is the change in frequency or wavelength of a wave if the source moves relatively to an observer. A common day-to-day example of this phenomenon is the change in pitch of a siren on a moving ambulance. When the ambulance approaches, the sound heard is higher than the original one; however, when the ambulance moves away, it is lower. The received sound is only the same at the moment when the ambulance passes the observer.

We use a buzzer on a rotating disc as the source and a static microphone as the observer in our experiment (see ⌾1).
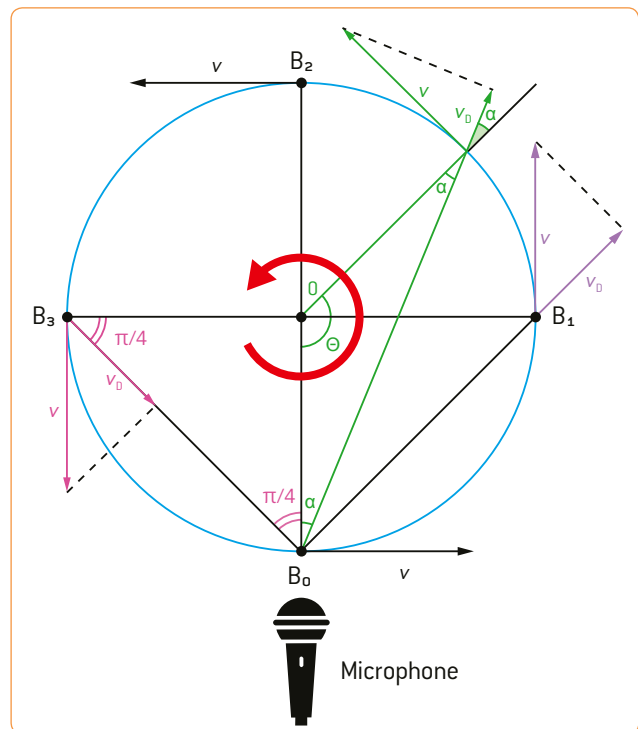
⌾ 1: The schematic of the experiment

As the disc rotates counter-clockwise (⌾1), the component of the velocity on the line of the chord, joining point B_0 with the point where the buzzer B is located every time, increases from zero to maximum at point B_1 and subsequently decreases to zero at point B_2. That velocity component is the actual receding velocity for the Doppler effect. From point B_2 to B_3, the velocity component, which now stands for the approaching velocity, increases from zero to maximum at point B_3 and then decreases again to zero at point B_0.

Calculate the linear velocity by applying the Doppler shift formula for a moving source at point B_3 and an observer at rest. The linear velocity remains constantly perpendicular to the radius of the circle and the angle of $\frac{\pi}{4}$ is determined by the geometrical properties of the formed right-angle and isosceles triangle B_3OB_0.

$$f = f_0 \cdot \left(\frac{v_s}{v_s - v_D} \right) \Rightarrow f = \frac{f_0 \cdot v_s}{v_s - v_D} \Rightarrow f \cdot v_s - f \cdot v_D = f_0 \cdot v_s$$

$$\Rightarrow f \cdot v_D = (f - f_0) \cdot v_s \Rightarrow v \cdot \cos\left(\frac{\pi}{4}\right) = \left(\frac{f - f_0}{f}\right) v_s$$

$$\Rightarrow v = \left(\frac{f - f_0}{f}\right) \frac{v_s}{\cos\left(\frac{\pi}{4}\right)}$$

f: measured frequency
f_0: emitted frequency
v: velocity
v_s: velocity of sound
v_D: receding/approaching velocity

As the implementation of a Fast Fourier Transform to extract the frequency content of the produced sound is well beyond the students' coding capabilities, free audio editing software like Audacity[3] will provide an adequate text file with all the necessary data.

<Further materials>

One more method that utilises a pitot-static tube system and a differential pressure sensor has been deliberately left out of the scope of this teaching unit to simplify matters, but all the required information is available online[4]. The online material offers a detailed description of the experimental setup, alternative construction ideas, along with theoretical documentation and step-by-step analysis of the procedures used.

<What the students/teachers do>

In the physics-related section of the teaching unit, the students will measure the physical quantities of circular motion at different radii and explore the Doppler effect. However, they will first design and assemble a basic experimental setup beforehand.

<The wooden disc setup>

The students will build the setup consisting of a wooden disc which is driven by a power drill and bears a buzzer connected to a 9V battery. An independent but closely situated infrared proximity sensor feeds the microcontroller a signal for every complete rotation, while a cheap microphone records the sound that is produced. The Doppler shift should ideally be audible for the chosen rotational speed, which should be kept low for safety reasons. [📷2 & 3]

Case for 9V battery

Buzzer
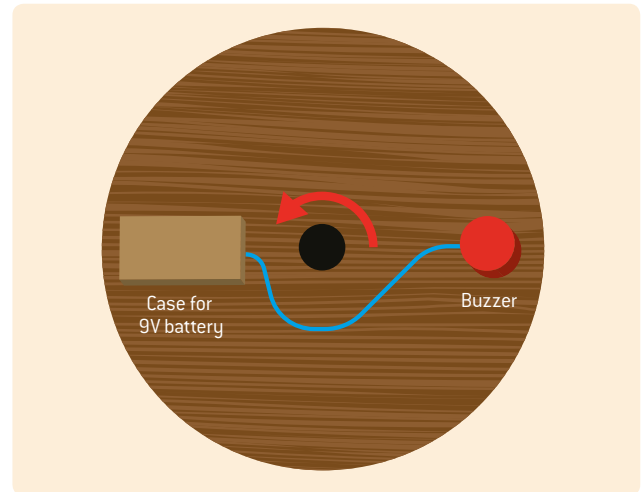
📷 3: Disc viewed from above

📷 2: Basic experimental setup

An attractive and student-friendly interface has been developed as shown in ◉4 to input all the required parameters and extract the calculated values.


◉ 4: The experiment's interface

The students need basic programming skills and some experience using block programming languages (such as Scratch or Snap!). We give the students a basic template to work their code to ensure that they focus on the teaching unit objectives and not on the user interface and the appearance of the program.

Therefore, we provide the basic template in a Snap![5] project .xml file and a work assignment paper to give the students basic instructions about the template form and outline what we expect from them. Both the template and the assignments are available online.[4]

The students will check and validate the acquired data, connect and communicate with the external devices, receive and process data from the sensors and write a simple serial search algorithm.

The finished program is also available for the teacher for download as a reference file[4]. ◉5 contains an example screenshot of the Snap4Arduino[2] programming environment. ◉6 contains the corresponding Nassi-Shneiderman diagram.
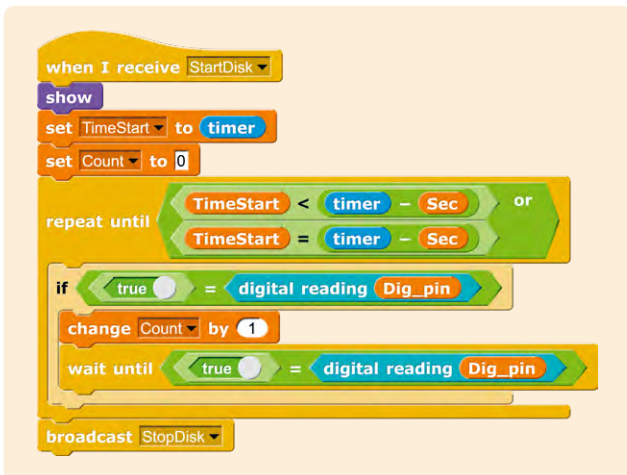

◉ 5: The calculation of the rotational period
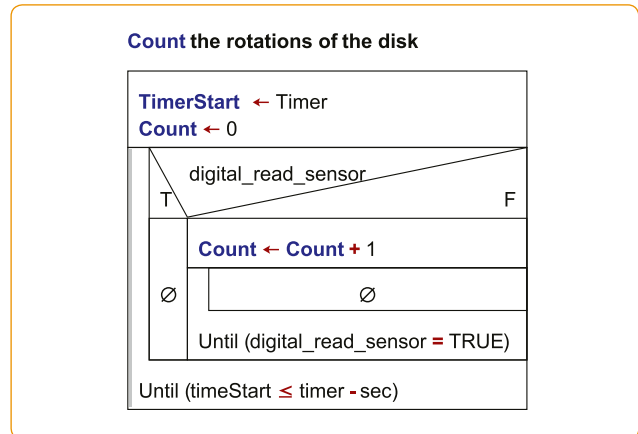
◉ 6: Nassi-Shneiderman diagram for period

As mentioned before, we recommend using a free audio editing software like Audacity[3] to extract the frequency content of the produced sound. The software provides an adequate text file with all the necessary data for the students to learn how to process a sound signal by means of a specialised software.

The signal import and essential processing is illustrated in ◉7−9, while ◉10 depicts a part of the final data export. To avoid in-depth analysis and to allow for a better comprehension from the students, a rough assumption has to be made here. The yellow highlighted frequency, which possesses the maximum level, is the buzzer's frequency at rest or the one measured at points B_0 and B_2, while blue and green represent those between our primary frequency shifts as the nearest peaks (◉10).
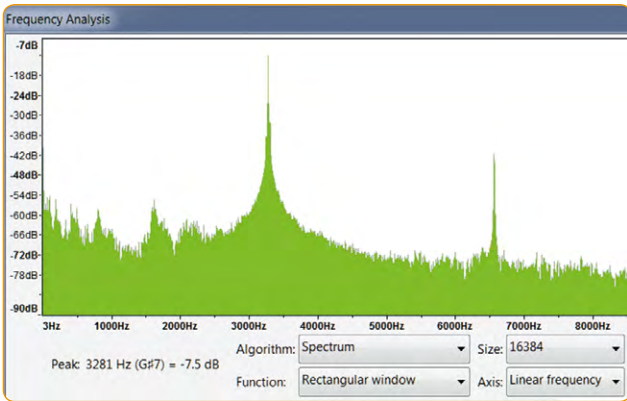
However, the proposed code searches only for the green highlighted, but for better accuracy it can be easily modified to find both. To speed things up, the data section could also be narrowed to only 50−100 values above and below the frequency of the maximum level.
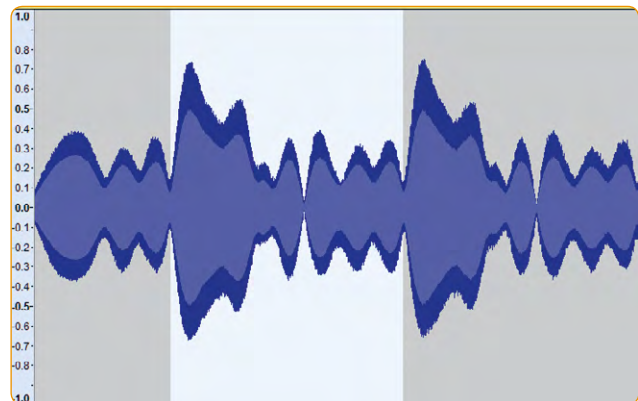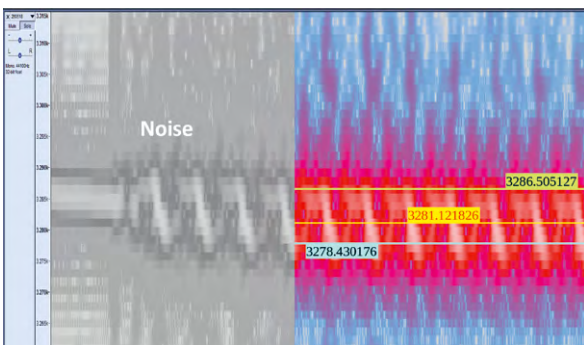

◉ 7: A recorded sound waveform
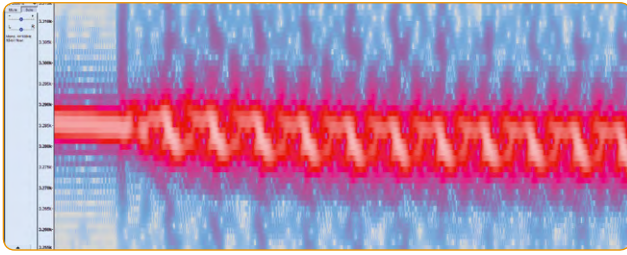
◎ 8: A spectrogram showing the Doppler shift

◎ 9: Frequency analysis by Fast Fourier Transform

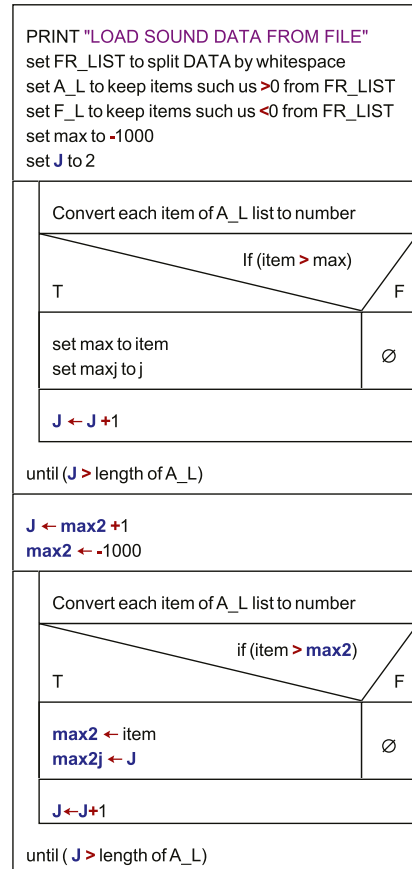| Frequency[Hz]	Level [dB]
3273.046875	-27.597595
3275.738525	-22.331339
3278.430176	-12.437067
3281.121826	-7.5547090
3283.813477	-10.041918
3286.505127	-9.7750780
3289.196777	-16.848948
3291.888428	-26.916197

◎ 10: Exported data

The sound spectrum data processing is shown in ◎ 11 & 12. Detailed information, e.g. about the used variables, is available online. [4]

◎ 11: The Doppler shift part of the experiment[4]

Sound Data Processing

```
PRINT "LOAD SOUND DATA FROM FILE"
set FR_LIST to split DATA by whitespace
set A_L to keep items such us >0 from FR_LIST
set F_L to keep items such us <0 from FR_LIST
set max to -1000
set J to 2
```

Convert each item of A_L list to number	
If (item > max)	
T	F
set max to item set maxj to j	∅
J ← J +1	
until (J > length of A_L)	

```
J ← max2 +1
max2 ← -1000
```

Convert each item of A_L list to number	
if (item > max2)	
T	F
max2 ← item max2j ← J	∅
J←J+1	
until (J > length of A_L)	

◎ 12: Nassi-Shneiderman diagram for sound data processing

‹Algorithm to use in other languages›

The basic template will allow easy transfer to any other programming language as long as there is a basic library for communication with the microcontroller. Hence, the choice of microcontroller will have no significant effect on the project.

‹Conclusion›

This is a low-cost project which is easy to assemble and operate; it will hopefully be interesting and stimulating for the students.

‹Cooperation activity›

The Science on Stage platform is all about exchanging teaching ideas and implementing innovative educational approaches. Co-teaching with Ilia Mestvirishvili and David Shapakidze, a superb partner team from Georgia, might prove to be challenging due to the distance and scheduling issues, but it has already allowed us to develop new techniques. Despite the common lack of a background in special needs education, it would be a good idea to modify the project to make it accessible to all students.

‹References›

[1] www.arduino.cc
[2] http://snap4arduino.rocks
[3] www.audacityteam.org
[4] All additional materials are available at www.science-on-stage.de/coding-materials.
[5] https://snap.berkeley.edu

↪ www.physicsclassroom.com/mmedia/circmot/ucm.cfm
↪ https://education.pasco.com/epub/PhysicsNGSS/BookInd-904.html
↪ http://hyperphysics.phy-astr.gsu.edu/hbase/Sound/dopp.html
↪ http://newton.phys.uaic.ro/data/pdf/Doppler_experiment.pdf
↪ https://manual.audacityteam.org/man/tutorials.html
(all December 2018)

‹Imprint›

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