Pi-Tap project

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Overview

The main goal of this project is to introduce students to various concepts of computer science and programming, such as scripting in python and data acquisition and processing. Along the way mathematical and seismological concepts will be taught/reviewed in order to create a working ”touch board” that runs on a Raspberry Pi, four sensors, and a PSoC 4. Initially we will have the students create a touch sensor along a line (one dimensional) before extending to the much harder two dimensional case. In each lesson we plan on having an exploration section, which are not necessary to complete but will teach additional concepts to keen students that have easily completed the main section of the lesson.

Topics

Data Acquisition

This section aims to teach about how analog data may be read into a digital computer to be processed.

- Analog signals
  - Analog to digital conversion
- Digital signals
  - Meaning of HIGH / LOW
- Binary representation of integers

Programming concepts

  - Print statements
  - Declaring and calling variables
  - Control-flow

- Reading inputs from a probe
- Using library methods

Data Logging and Processing

This section aims to teach how large amounts of data can be used to create graphical representations which are easier to present, and how filtering the data can lead to better results.

- Sample rate
- Interrupts vs. polling
- Data tables / Python arrays
- Averaging filter - moving average
- Recording data to an array over time - `for` loop
- Outputting a CSV file (likely using Python `csv` library)
- Producing a graph in Excel from the imported CSV data

Programming concepts

- Loops
- Arrays
- File access

Maths

This section overviews the maths necessary to complete this project.

- Linear equations such as $y = mx + c$
- Slope defined as "rise over run"
- Distance, velocity and time relations: $d = vt$
- Regression and estimating the line of best fit
- Pythagorean Theorem and how it can be used to find the distance between two Cartesian points
- Data collection and plotting

Programming concepts

- Single-parameter functions such as doubling, area of a circle
- Multi-parameter functions such as area of a rectangle
- Return values

Physics and Seismology

Overview of seismology/science concepts used.

- Transverse vs. Compression waves
- S vs. P waves
- Wave velocity in different mediums - experiment with measuring this
- Amplitude/intensity is independent of the propagation velocity
- How this project could be used to "detect" an earthquake

Lesson Plan Outlines

Lesson 1 - Digital Data Input and Introduction to Python

Learning Objective

- How can we use a computer to read data from sensors?
- How can we read digital sensors with a Raspberry Pi and Python?

Starter

- Class discussion about what things we could read into a computer, collect ideas on whiteboard. E.g. sound, temperature, button presses
- Discuss which of these might be digital (ON/OFF) and how you can tell, e.g. button is digital because it can only have 2 values (on or off), whereas a temperature sensor is likely to not be digital since the temperature can take many values, and there is no clear role of on/off.

Main development

- If students have never used Raspberry Pi before, follow the Getting Started With Raspberry Pi lesson
- Demo program which reads a single value and outputs it to the terminal. Worksheet explains each line in detail
- Have students connect a button to the Raspberry Pi and read the value using the demo program
- Worksheet guides students through modifying the program to use conditional statements to print two different things depending on whether the button is pressed or not

Plenary

- Recap what digital values are
- Discuss why the Raspberry Pi is useful for reading sensors

Lesson 2 - Analog Data Logging and Graphing

Learning Objectives

- How can we read analog values into a digital computer?
- How can we record data over time and produce a graph from the results?

Starter

- Discuss what an analog voltage is (make comparison to digital values from previous lesson)
- Discuss ideas of sensors which might be analog, such as temperature, pressure, joysticks, distance sensors

Main development

- Ask how you might represent an analog voltage as a digital signal, give the example of a 1-bit converter which is HIGH above VDD/2 and LOW below that
- Introduce the idea of A/D resolution, where more bits means a higher precision. Students complete an exercise of drawing the output from a 2-bit A/D converter given an analog waveform
- Reading an analog sensor using Python and a Raspberry Pi. Have students connect a potentiometer to the board and read the value. Possibly recap last lesson by storing result in a variable and using conditionals to act upon the value
- Using loops - motivation: how could I read 10+ values and print them without having to type lots of code
- Worksheet guides students through modifying the code to use a for-loop to read and print a certain number of data points, and using `time.sleep()` to wait some time between readings
- Students change the delay in the loop to experiment with sample rate, and understand the effects of too high / too low
- Worksheet provides demo code to plot the data from the array onto a graph, likely using matplotlib and a wrapper script which will be provided
- Using `matplotlib` to produce graphs in python. We may provide a wrapper script which simplifies this process

Plenary

- Discussion of pros/cons of having higher resolution in an analog-to-digital converter: pros are better precision, cons include cost, size, speed, power. Mention that many datalogging applications will trade power and speed for more precise readings

- Discussion of what happens when the sample rate is too high or too low, and how these might affect a remote datalogger which must run on battery with limited storage space

Extension

- Worksheet guides students through using Python arrays to store the readings to be dealt with later

- Exporting a Python array into a .csv file using Python's csv library, possibly provide the code and explain it

- Using Excel to produce a graph from the .csv data

Lesson 3 - Introduction Maths and Functions

Learning Objective

By the end of this lesson students should have a grasp on Python functions, and will have written functions that can identify the TDOA given a location and the location given a TDOA.

Starter

- Review of linear equations and their properties.
- $d = v \times t$. Have examples of these types of questions such as finding the "time difference" of arrival of one person running to the left and one person running to the right to targets.

Main Activity

- Introduce students to a Python function that can double an input.
- Using a time library, show them a function that finds how old they are in seconds if they enter their birthday.
- Show how functions can have a variable number of parameters such as zero, one, two inputs.
- Discuss functions that do not have a return type.
- Have students write three function that finds one of distance, time, speed given the other two.
- Write two function for the one dimensional case: given the velocity and: a time difference, find the position along the line:a position, find the time difference.
- What does it mean if we input a non-numerical value for the functions above? Introduce control statements (if/else) and have students make sure their area finding function only takes in numbers. Have it print an error if any inputs are invalid.

Plenary

- Why are functions useful?
- Can the TDOA be negative? What does it mean if it is negative?
- What is the maximum/minimum possible TDOA? What are the possible values for the position?

Extension

Have the students modify their TDOA vs position functions to include control statements. Check to see that their TDOA and position are within the allowed range.

Lesson 4 - Seismology/Physics

Learning Objective

In this lesson students will explore the different properties of waves and their behavior in different mediums and be able to relate this to the seismic waves created by earthquakes. They will then conduct an experiment by timing how long it takes for a transverse wave in different density liquids to travel a certain distance.

Starter

- Introduce the concept of a wave
- Talk about transverse vs compression waves. S waves vs P waves during an earthquake.

Main Experiments

- Have a slinky set up. Have students try to create transverse waves and longitudinal waves in the slinky. Perform timing measurements on how long it takes each wave to traverse the slinky.
- Perform the pond experiment. Have three trays of solutions of water and corn starch, each with differing density. Dropping a rubber ball from an initial height, have the students measure the time it takes for a wave front to travel from the center to the edges. Drop the rubber ball from a higher point and perform the same measurement. Do this for each tray of solution.

Plenary

Ask the follow up questions

- Do transverse or longitudinal waves generally travel faster? Hence, ask if S waves of P waves travel faster.
- Are the waves created in the plate longitudinal or transverse?
- What is the relation between the ball height and the time it took the wave to reach the edge of the tray?
- What is the relation between the density of the solution and the time it took the wave to reach the edge of the tray?

Extension

Have students identify more examples of longitudinal waves and transverse waves. What is sound? In addition ask them what property of the wave is dependant on the height the ball is dropped from.

Lesson 5 - Wave velocity and One Dimension

Main Objective

By the end of this lesson the students will have implemented the one-dimensional piTap and can control the cursor along a line.

Starter

- Have students submit their functions from lesson 3 and have it set up on the pi.
- Show them the code for the mouse movement and discuss what it does.

Main Activity

- Set up the one dimensional case by setting the sensors a known distance apart. Have them tap on the board to find several TDOA to find the velocity of the wave in the board.
- Students can play/experiment with the board and see that they are able to control the mouse with taps.
- Distribute a table of various positions vs the theoretical TDOA associated vs the experimental TDOA. Have students choose several points and using their functions find the theoretical TDOA.
- Tap along the line the positions from the table and record the experimental TDOAs.
- Produce an excel graph or scatter plot of the position vs experimental TDOA and have them draw the line of best fit through the points.

Plenary

- Why are the experimental and theoretical values different?
- What happens if they tap to the left or to the right of the sensors?
- Have students find the equation of their line of best fit and compare it to their theoretical equation.

Extension

What happens if we do not tap along the line. Brainstorm ideas on how they could uniquely detect a point in two-dimensions.

Lesson 6 - Two Dimensions

Main Objective

Students should know how to find the distance between two cartesian points and have a function to do so. We introduce the python math library.

Starter

- Remind students what the Pythagorean theorem is and how they can use it to find the distance between two cartesian points.
- By hand, do several examples of the Pythagorean theorem and distance calculations.
- Review the velocity, distance, time relationships.

Main Activity

- Have students program a function that takes in four inputs x1,y1 and x2,y2 and find the distance between them. Introduce them to the python math library for square roots.
- Extend their function to find the TDOA relative to the origin (with the four sensors set up) and export it as an array.
- Set up the two-dimensional case using the code provided and let students play around with it - essentially creating a touch screen!
- Output the recorded TDOA and have them compare it to the value their function predicts.

Plenary

- How could scientists use a similar set up to detect where earthquakes occur?
- Given the TDOA, how can we predict which quadrant the point is in?
- Why are we using four sensors instead of three?
- Why is it important that the material of the board is isomorphic through out?

Extension

- Explore by hand the Babylonian method for iteratively calculating square roots and have them write a square root function (using a fixed iteration). Replace the square root library function they called in their distance code.
- Read an article that briefly ELI5 how the position tracking in the two-dimensional case works.