First Steps with Arduino

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Project Name: Synergy
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Course Outline

The course "First Steps with Arduino" aims to familiarize the students with the capabilities of the world's most popular platform for amateur electronics. It introduces the basic usage of digital and analog GPIO pins for reading the state of sensors and controlling different electrical components. It lays down the fundamentals of working with resistors, diodes, transistors, relays, etc. as well as the principles of drawing electric circuit diagrams.

Available Hardware:

- 1 Genuino Uno board
- 1 USB cable A to B
- 1 breadboard with 840 tie points
- 70 jumpers of various length
- 6 LEDs (2 green, 2 yellow, 2 red)
- 3 push-buttons 6x6 mm
- 1 light-dependent resistor (LDR)
- 1 piezoelectric buzzer
- 3 potentiometers 10K ohm
- 10 resistors 220 ohm
- 10 resistors 10K ohm
- 1 electrical motor
- 1 H-bridge motor driver
- 1 MOSFET IRF530
- 1 bipolar transistor BC547
- 1 rectifier diode 1N4007
- 1 relay

Project Requirements

The formal requirements for the project are that the students use at least one of each type of input and output device: one digital input, one digital output, one analog input and one analog output.

Project Description

Basic workflow

The system simulates an environment in which energy from an external source is collected in a pool. The pool is used to power a motor which performs useful work. The motor needs to operate within certain constraints, meaning that if the accumulated energy in the pool is too low or too high it will shut down automatically to prevent damage.

The user has several instruments to exert a measure of control over the environment: 1) buttons to turn the motor ON or OFF; 2) a button to toggle the motor's direction of rotation; 3) a regulator to change the motor's rotation speed and energy consumption; 4) a valve to release energy from the pool.

Several sensors provide information about the system which the user can utilize: 1) a yellow LED signaling low energy level in the pool; 2) a green LED signaling optimal energy level in the pool; 3) another yellow LED signaling higher than recommended energy level in the pool; 4) a red LED signaling a dangerously high energy level in the pool; 5) two LEDs (green and red) signaling the net inflow in the pool – green for net gain and red for net loss of energy; 6) a piezoelectric buzzer signaling that the motor is OFF; 7) various log messages in the serial monitor providing information about the system's state and events.

Additional information is available in the Workflow Overview section.

Pin Map

- Digital GPIO:
    - 0 (RX) – free
    - 1 (TX) – free
    - 2 – motor off sound signal (piezoelectric buzzer)
    - ~3 – motor ON push-button
    - 4 – motor OFF push-button
    - ~5 – net energy loss LED
    - ~6 – net energy gain LED
    - 7 – low pool energy level yellow LED
    - 8 – high pool energy level yellow LED
    - ~9 – motor speed controlling pin (EN)
    - ~10 – motor 1A pin
    - ~11 – motor 2A pin
    - 12 – critical pool energy level red LED
    - 13 (with built-in 220 ohm resistor) – optimal energy level green LED
- Analog IN:
    - A0 – energy source (LDR)
    - A1 – release valve 10K ohm potentiometer
    - A2 – motor regulator 10K ohm potentiometer

    - A3 – toggle motor rotation direction push-button
    - A4 – free
    - A5 – free

Used Hardware

- Genuino Uno board
- USB cable
- breadboard
- 6 LEDs
- 5 resistors 220 ohm
- 3 push-buttons
- 4 resistors 10K ohm
- 1 piezoelectric buzzer
- 2 potentiometers
- 1 LDR
- 1 electrical motor
- 1 H-bridge motor driver
- 41 jumpers

Workflow Overview

System Description

The setup simulates a relatively simple system in which an energy source emits a variable amount of energy which is stored in a pool with limited capacity. The collected energy is used to power a motor which performs a useful task. If the energy in the pool is too low or too high the motor will shut down to prevent damage. The user can exert some control over the system by regulating the motor's consumption, turning it ON or OFF and releasing energy from the pool. In order to decide on the best course of action to keep the system running, various sensors provide useful information about the system's state.

Energy Source

The energy source is assumed to be an environmental variable which is outside the user's control. In this setup, a light-dependent resistor (LDR) is used as the source, which provides a (supposedly) randomized inflow of energy. The readings from the LDR are taken and added to the energy pool. E.g., a reading of 400 (range is 0-1023 inclusive) adds 623 units of energy in the pool.

Additionally, at an interval of 1 sec, a random amount of energy is added to the pool.

Pool Characteristics

The pool has a total capacity of 5 000 000 units of energy. The following ranges determine its current state:

- Empty: 0 – 499 999 (causes motor shutdown)

- Low: 500 000 – 1 199 999
- OK: 1 200 000 – 2 499 999
- High: 2 500 000 – 3 499 999
- Critical: 3 500 000 – 3 999 999
- Full: 4 000 000 – 5 000 000 (causes motor shutdown)

Pool Status LEDs

Four LEDs are used to signal the state of the energy pool. Only one of them can be active at any given time.

- Low Energy Yellow LED – the leftmost LED is turned on when the energy in the pool is below optimal levels. It starts flashing with an interval of 1 second. When low energy is detected, the motor automatically enters low power mode (25% of maximal speed) and the speed regulator no longer has any effect until the energy level is restored within safe levels. When this LED is on, the user is expected to undertake corrective measures to increase the energy level in the pool by closing the release valve so as to increase the net gain of energy.
- Optimal Energy Green LED – the green LED between the two yellow LEDs is permanently on (no flashing) when the energy levels in the pool are within optimal ranges and the motor is ON. In case the motor is OFF, the LED flashes with and interval of 1 second, meaning the user can turn the motor ON again after previously being powered off.
- High Energy Yellow LED – the yellow LED to the right of the optimal energy green LED is turned on when the energy in the pool is higher than optimal. It flashes with an interval of 500 ms. The user is expected to take corrective measures in order to decrease the net gain of energy in the pool by taking one or more actions that increase the outflow – increase the motor’s speed (hence energy consumption) or open the release valve.
- Critical Energy Red LED – the rightmost red LED is turned on when the energy level in the pool is dangerously high. It flashes with an interval of 250 ms. Note: unlike the low energy state, the motor’s speed is not adjusted automatically to correct the pool’s energy level. The user is expected to take corrective measures in order to decrease the net gain of energy in the pool by taking one or more actions that increase the outflow – increase the motor’s speed (hence energy consumption) or open the release valve.

Motor Control Buttons

There are three push-buttons which control the motor’s state:

- ON button – leftmost on the board. It only has an effect if the motor is OFF and the energy level in the pool is within optimal ranges.
- OFF button – to the right of the ON button, the middle of the three buttons. It only has an effect if the motor is ON; works regardless of the pool’s energy levels.

- Toggle Direction button – rightmost on the board, to the right of the off button. Changes the direction of rotation of the motor. It only has effect if the motor is ON. Does not affect the motor's speed or consumption. An H-bridge driver is employed in order to make the direction switch possible. The default direction of rotation upon power-up is clockwise. Direction is preserved during power-offs, i.e. if the motor is rotating counter-clockwise when an event (user request or automatic shutdown) causes it to power off, it will continue rotating counter-clockwise when it's next powered on.

Motor Speed Regulator

The motor speed regulator is a 10K ohm potentiometer which controls the speed of the motor. There are four speed levels, expressed as a percentage of the maximal speed – 25%, 50%, 75% and 100%. The motor cannot be turned off using this regulator, this can only be achieved with the OFF button. If the energy level in the pool is below optimal, the motor enters low power state (25%) and the regulator has no effect until safe energy levels are achieved.
The following value ranges of the potentiometer's readings correspond to the given speed levels of the motor (level increases clockwise, leftmost position is 1023, rightmost is 0):

- between 0 and 256: 25%
- between 257 and 512: 50%
- between 513 and 767: 75%
- between 768 and 1023: 100%

Release Valve

The release valve is a 10K ohm potentiometer which releases energy from the pool. When the valve is fully open (leftmost position) 1023 units of energy are released from the pool at each loop iteration. When the valve is closed (rightmost position), no energy is released. Positions in between release a proportional amount of energy, e.g. if the valve is halfway open (about 512 read from analog IN), a proportional amount of energy is released – 512 units.

Net Inflow LEDs

Two LEDs are positioned near the release valve to indicate whether the system experiences net gain or net loss of energy.

- A red LED is placed to the left of the valve which signals that the system is losing energy; it is purposefully placed to the left to remind the user that turning the valve counter-clockwise will increase the outflow and most likely lead to a net loss of energy.

- A green LED is placed to the right of the release valve which signals that the system is gaining energy; it is purposefully placed to the right to remind the user that turning the valve clockwise will decrease the outflow and most likely lead to a net gain of energy.

The two LEDs cannot be on simultaneously and their luminosity roughly corresponds to the magnitude of the net inflow of energy, e.g. a brightly lit red LED means the system is losing energy relatively fast, and a dim green LED means the system is gaining energy at a somewhat moderate pace.

The LEDs update at an interval equal to the info log interval in order to provide consistent (although somewhat delayed) information.

Idle Motor Sound Signal

A piezoelectric buzzer is used to signal that the motor is in an OFF state. The signal persists until the motor is turned ON and is not affected in any way by the energy level of the pool.

Logs

Logging messages are printed to the serial monitor in order to present information to the user. There are three types of messages:

- **Error <E>** – signal an abnormal situation. In this category fall events like:
  - Motor auto shutdown due to low or high energy in the pool;
  - User attempt to turn ON the motor when the energy level is not within accepted parameters;
- **Warning <W>** – signal situations that may require the user's attention like:
  - The motor entering low power mode;
  - A button was pushed without the necessary preconditions being met – the ON button pushed when motor is already ON, the OFF or the toggle button pushed when motor is OFF;
- **Information <I>** – signal information that the user may find useful. There are two types of informational messages – scheduled and spurious. Scheduled messages happen at predetermined intervals and provide general information about the entire system. Spurious messages are printed in response to a specific event or user interaction. Among the information messages there are:
  - General Info – shows an overview of the system at an interval of 3 sec. Includes: motor state and speed, pool energy level, net inflow of energy with data about consumption and release of energy, release valve position;
  - Motor State Change – when the user performs a valid change in the motor's state or direction of rotation;

Code Overview

Custom Header Files

Custom headers were created in order to separate *#define* macros from the program logic and reduce the amount of source code in the main program file. *#define* directives are used to reduce the memory occupied by global variables and to eliminate "magic numbers" whenever possible.

env_limits.h

Contains macro definitions of environment limits like the maximal speed of the motor, the lower and upper bounds of the optimal pool energy levels and others.

pins.h

Contains macro definitions of the pin numbers (see Pin Map).

Functions

The code is separated into numerous functions which aim to achieve a good level of abstraction (as far as this is possible within a single source file) and maintainability. This has the positive effect of making the code understandable. For example:

```
collectEnergyFromEnvironment();
checkUserIntervention();
expendEnergy();
signalEnergyLevelAndNetGain();

if (motorSpeed == ZERO_SPEED) {
   signalMotorOff();
}
```

This reads almost like natural English and makes the program logic clearer.

The built-in functions *strcpy(), random(), min(), map(), millis(), Serial.print(), Serial.println(), digitalWrite(), digitalRead(), analogWrite() and analogRead()* were used.

Debounce and Timeouts

All three push-buttons are debounced. Additionally, several timeouts were defined for various events (logs, LED blinking, system stability) in order to avoid excessive logging or uncontrollable update of the system's state where the user would find it difficult to exert control.

Logging

Initially, an attempt was made to use the sprintf() C library function to make for a prettier formatting of the logging function, but that attempt was unsuccessful. Therefore, a series of Serial.print() finished off with a call to Serial.println() were used instead.

For events, logging happens inside the corresponding functions, e.g. the function which puts the motor in low power mode logs this event.

Appendix 1. Breadboard Diagram