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Smart Door Lock: Exploring Embedded Machine Learning for ISU Curriculum

Motivation & Problem Statement

Iowa State University offers both embedded systems classes and machine learning classes but does not offer machine learning classes in the context of embedded applications. Therefore, students need a project or course, with real world applications, that teaches them machine learning through the lens of an embedded system. Our goal was to create such a project that could be integrated into the ISU curriculum.

Solution

We have chosen a Smart Door Lock that recognizes a specific word and locks/unlocks a door, and we created corresponding lesson plans for implementing this project in a laboratory setting.

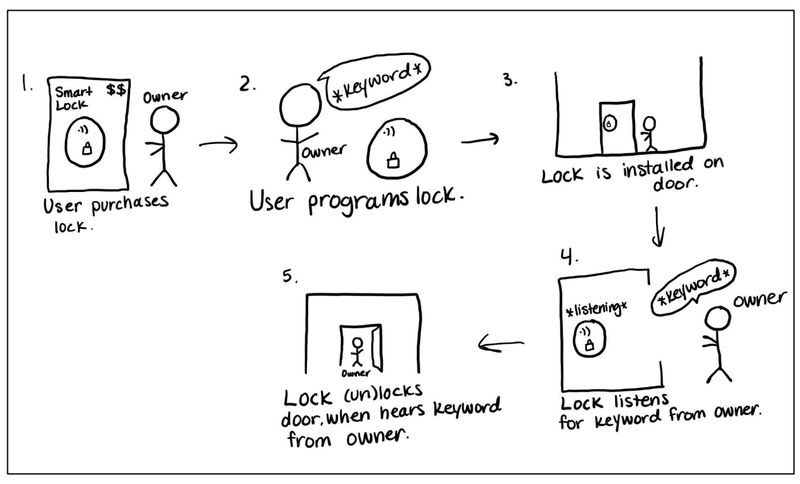

Figure 1: Concept Sketch

Users & Uses

Students:
- Laboratory component as part of ISU course
- Independent study
- Undergraduate research

Professors & TAs:
- Laboratory component for their course
- Resource to provide to students to learn about embedded machine learning

Design Requirements

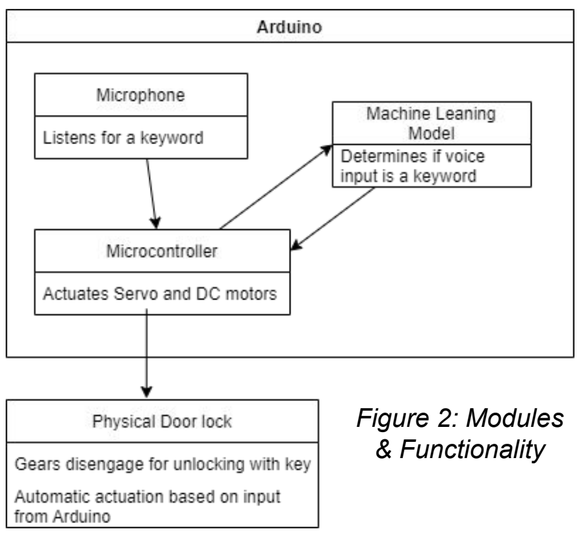

Figure 2: Modules & Functionality

Functional Requirements:
- Door (un)locks with correct keyword
- User could still open door manually
- System takes in real time data from the user

Operating Environment:
- Classroom/Laboratory

Non-Functional Requirements:
- Incorporate machine learning into an embedded system
- Appropriate technical complexity for ISU course
- Users must agree to have voice recorded

Engineering Constraints:
- 90% keyword accuracy
- (Un)locks door in 5 seconds
- Small enough to fit on door lock
- Memory & computational power of Arduino Nano 33
  - 256 KB SRAM
  - 1 MB Flash

Relevant Standards:
- AI & Autonomous Systems
  - IEEE P7001 (transparency)
  - IEEE P7002 (data privacy)
- ANSI Grade 3
- BHMA Residential Security Grade C

Design Approach

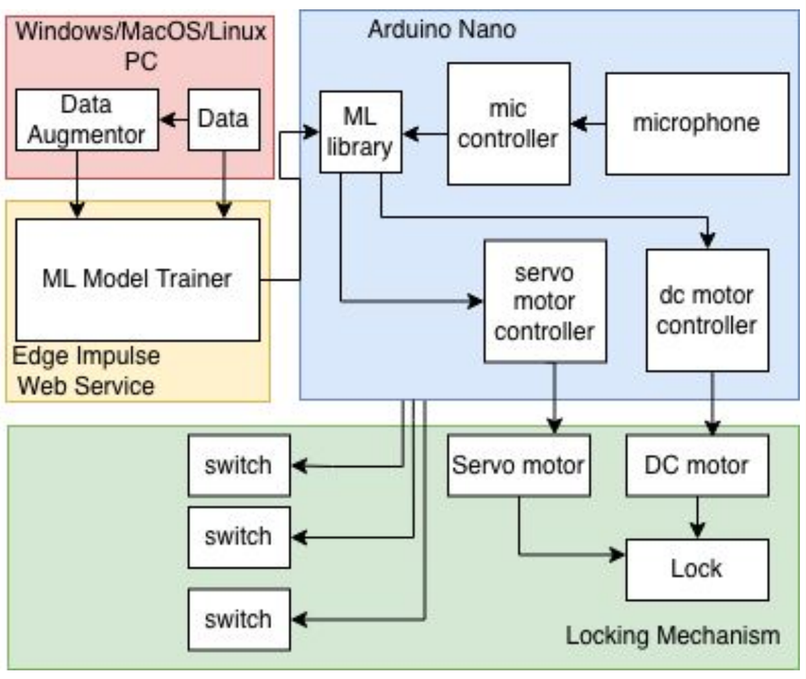

Figure 3: Block Diagram

Machine Learning Model

Requirements:
- Take input as real time voice data from the Arduino mic
- Output as either Marvin, House, background noise, or unknown

Details:
- Keywords: Marvin, House
- Edge Impulse used
- 20 distinct, real voices
- 10,157 total samples

Design Choices:
- Using Edge Impulse
- 1D Convolution for ML model
- Real to synthetic data ratio
- Edge Impulse parameters

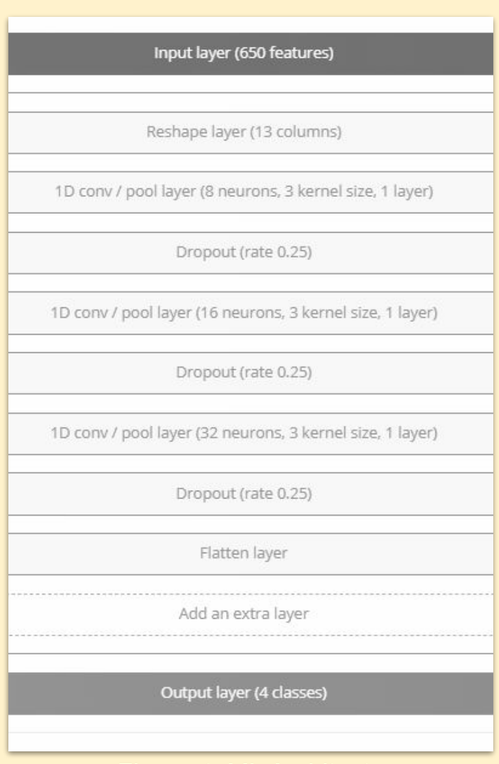

Figure 4: ML Architecture

Training:
- 4:6 real:synthetic data
- 80% of total data
- Learning rate of 0.0005
- 500 training cycles

Testing:
- 20% of total data
- Done in Edge Impulse
- Confidence level of 0.6

Results:
- 1 ms latency
- 6.5K RAM usage
- 37.6K flash usage
- Final accuracy of 89.39%

Limitations:
- Not 100% accurate, which introduces security concerns in real world application

Circuit

Requirements:
- Switches control motors to (un)lock door
- Circuit is not externally powered

Details:
- Arduino to program servo & DC motors
- Wired on breadboard but have PCB file
- PWM used for DC motor

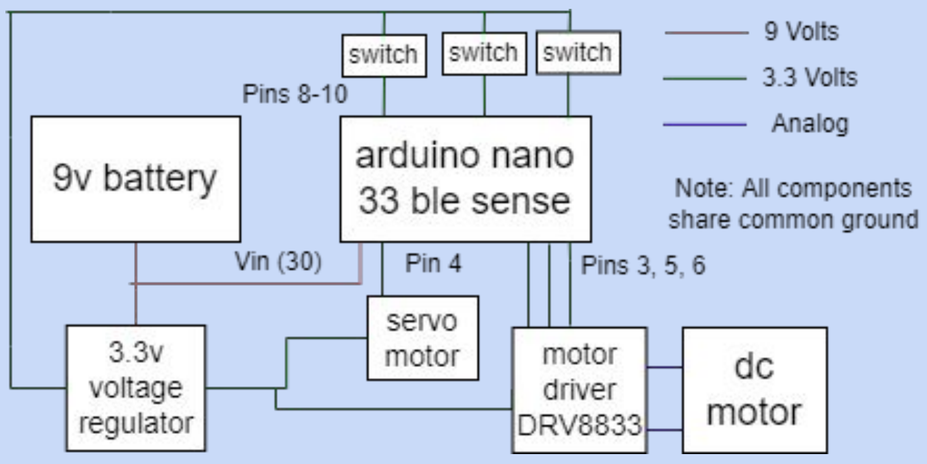

Figure 5: Circuit Diagram

Design Choices:
- Arduino Nano 33 BLE Sense
- Motors & switches

Testing:
- Unit testing for servo & DC motor was done in parallel with circuit system testing
- Testing Environment: Arduino Serial Monitor and physical
- Results show both motors moving in the correct directions with triggering of the switches

Physical Model

Requirements:
- Must (un)lock door with switches
- 20 oz-in of torque on drive shaft

Details:
- 2.16:1 gear ratio to increase torque
- 3D printed pieces

Design Choices:
- Standard single cylinder lock
- Easily printed parts

Testing:
- SolidWorks Assembly motion study
- Integration tests with each 3D printed piece
- System testing with final prototype
- Results: system constantly locks successfully, gears sometimes will skip when unlocking

Limitations:
- 3D printing tolerances leave some play between parts causing backlash

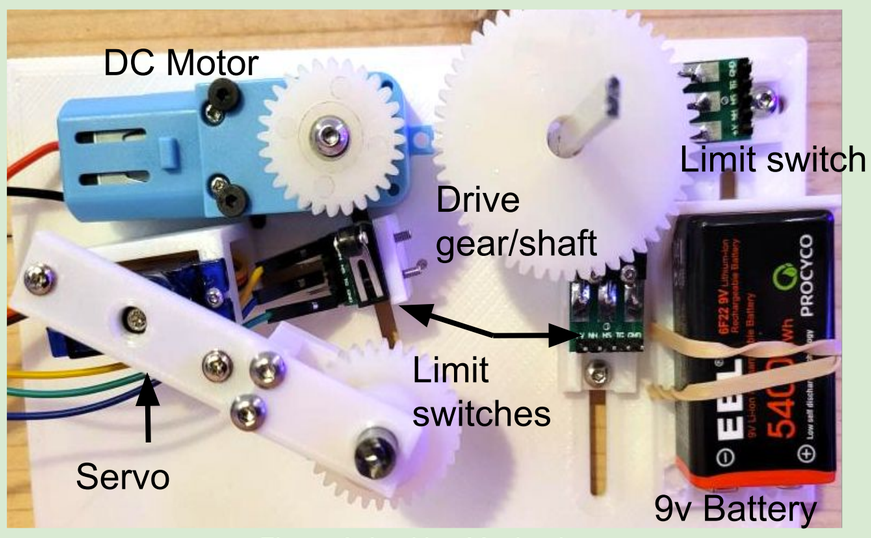

Figure 6: Locking Mechanism

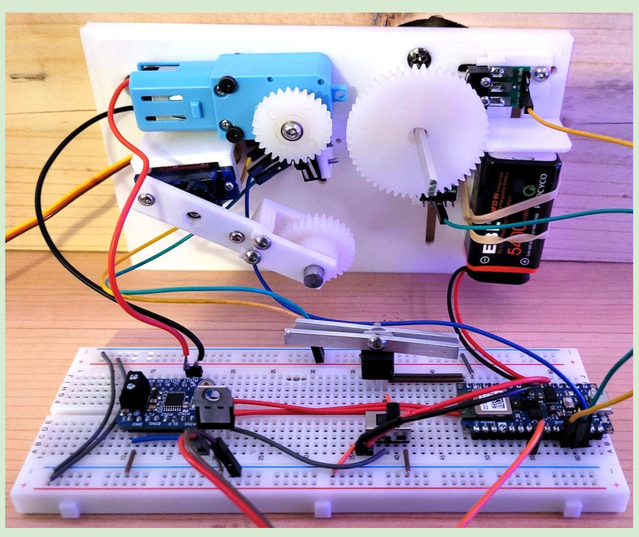

Figure 7: Full Physical System

Security:
- ML Model not 100% accurate - not secure enough for some real world scenarios
- Physically has same security as lock, which has standards that are consumer grade
- Implemented in a classroom setting for educational purposes, and therefore security implications have been noted but not fixed

Lesson Plans

Figure 8: Lab Activity Flow Chart