UNIVERSITY OF MICHIGAN

Hands-free Typing and Text-to-Speech using Eye-Tracking

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Contents

Project Description

Introduction

- Our project allows people with motor disabilities (of the hands and/or face) to communicate by typing visually
- Generally, uses:
    - Image processing
    - Computer vision
    - Machine learning (e.g., clustering)
- Implementable on cheap hardware
    - Raspberry Pi 4
    - Picamera (vol. 2)
    - Mini-speaker

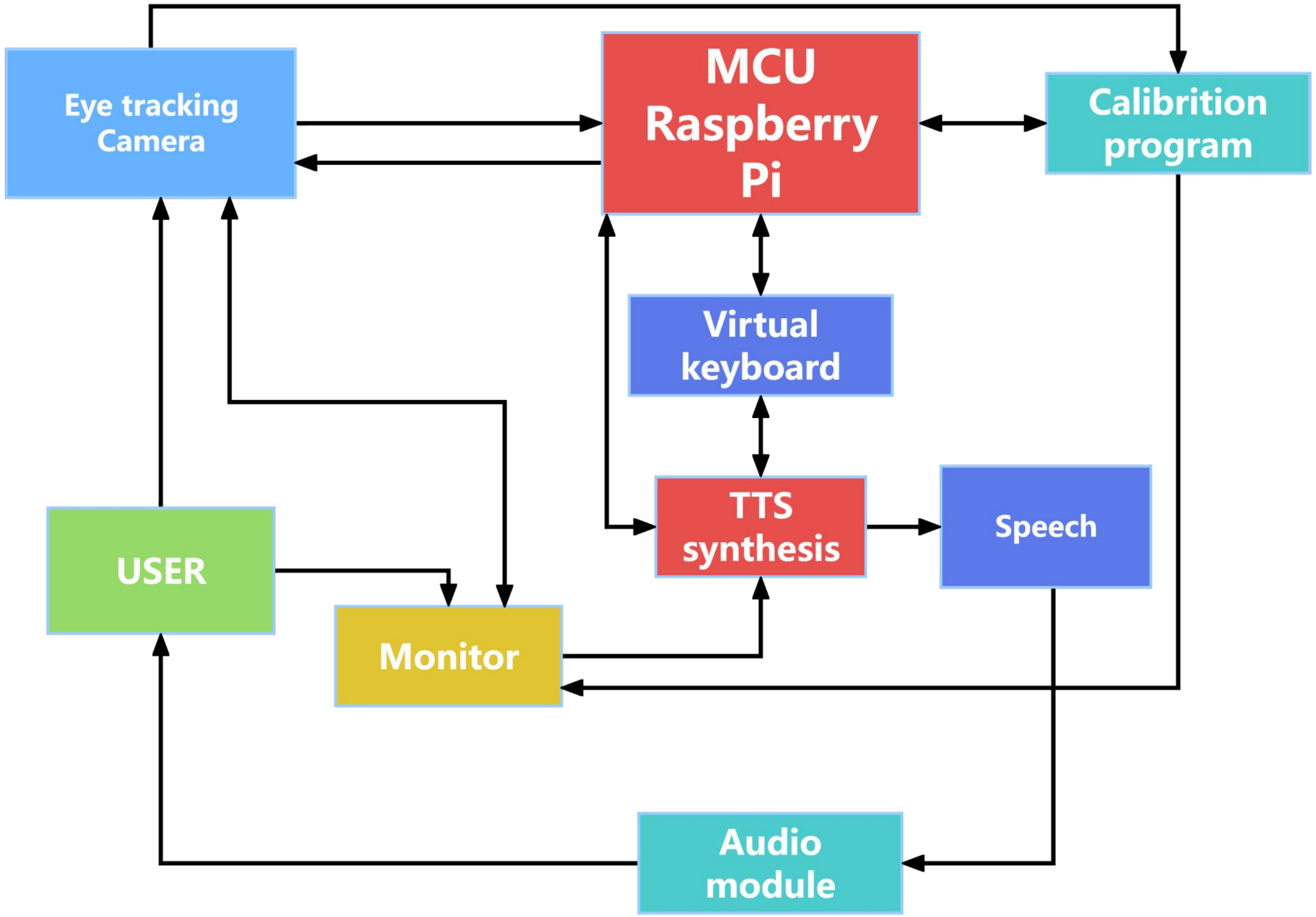
Motivation

- People with hand disabilities or more general movement disorders have difficulty typing
  - e.g., Parkinson's, ALS
- Our project allows them to type with their eyes
- Some people also can't speak due to facial muscle disorders
- Our project includes a Text-to-Speech (TTS) component

Figure:
Stephen Hawking with his IBM machine

Gaze Tracking + TTS System Setup

System Diagram



Demo

Implementation & Results

Eye Tracking Architecture

Initial Version

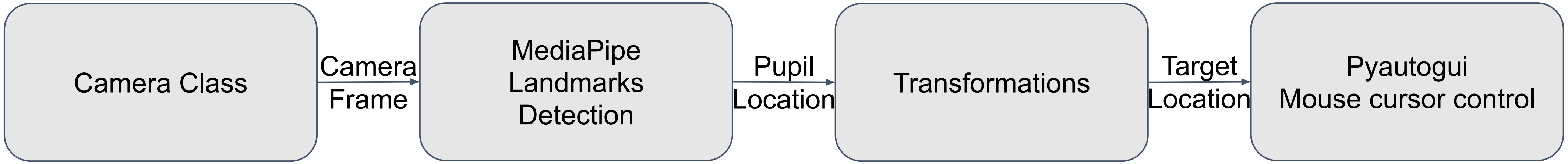
- Camera frame to Facial Landmarks (using dlib model)
- Isolate eyes from frames and locate pupil (using openCV contour)

- Pupil Location (X,Y) to Target on Screen (X,Y)

- Could be integrated with applications easily

Eye Tracking Architecture

Improved Version



- Produce camera frame
- Help make it smoother to debug on PC and deploy on PI due to PC and PI using different camera class

- Camera frame to Facial Landmarks
- More stable and faster than dlib solution
- Directly produce pupil locations

- Code refactor to enable easy switch of transformation function by just choosing the desired transform class
- Added perspective transformation (choice in final version)
- **EMA** filter

- Could be integrated with applications pretty easily

Calibration

Transformations from pupil location to screen target location needs calibration

Display Calibration Points and record pupil locations → Data Cleaning → Calibrate Transformation Parameters

Display Calibration Points and record pupil locations

- 3 Points for affine transformation
- 4 points for perspective transformation
- Maybe multiple points for neural networks

Data Cleaning

- Use clustering-like method to filter outliers
- Assume gaussian distribution
- In each iteration, calculate the means and variation, filter-out points with low possibility
- Redo the iterations until no changes

Calibrate Transformation Parameters

- Use the data to calculate transformation parameters
- calculate the transformation matrix in the case for affine and perspective transformation

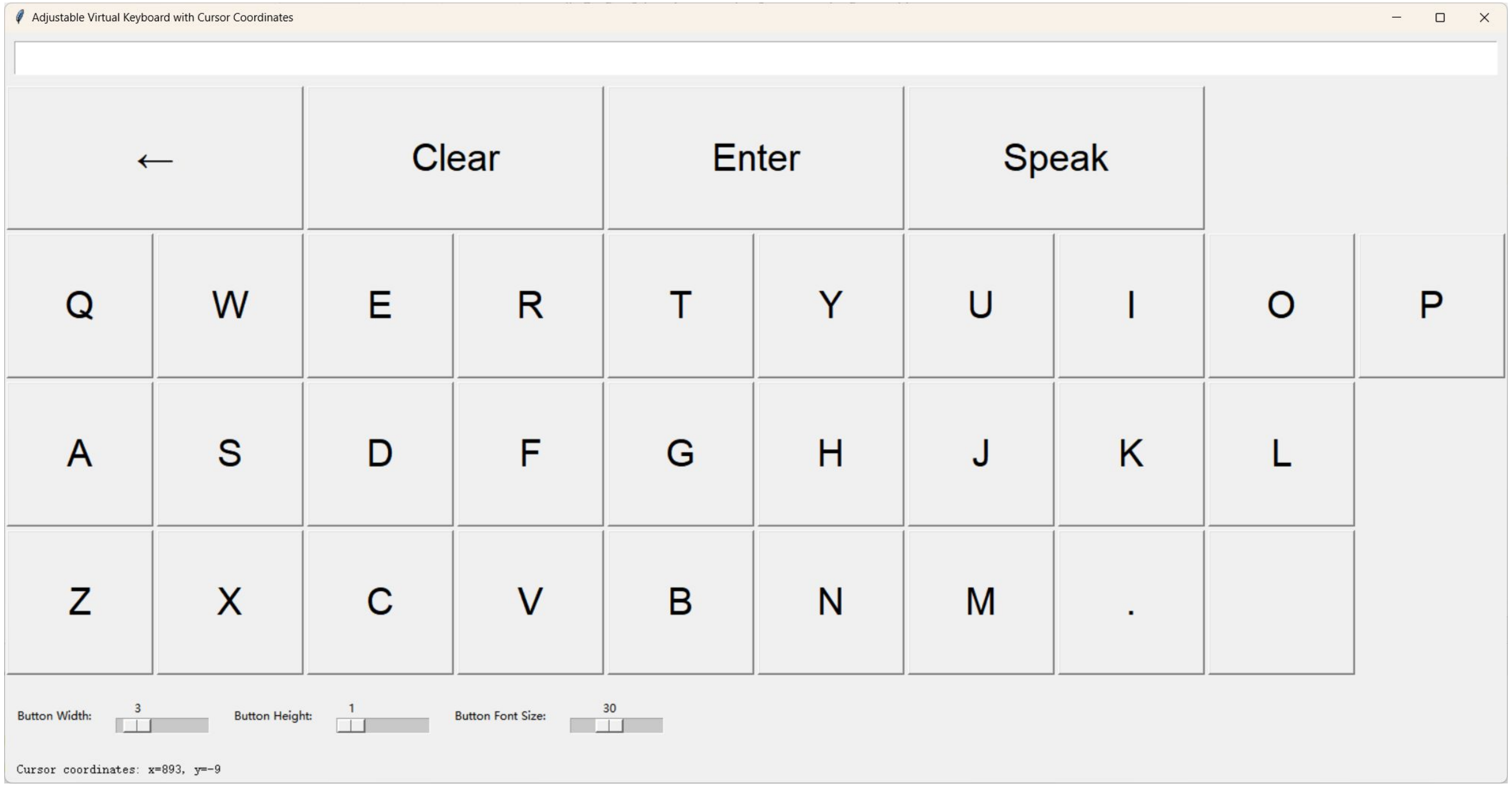
Attempts & Future Discussion

- Attempted to use machine learning methods for the transformation
- Pupil locations w/ other landmarks as input
- Doesn’t work at all
- Hard to obtain training data set
- Networks like DNN, Transformers might not be suitable for such task

- **Future Discussion:**
- Near-infrared camera
- High-resolution & high-frame-rate camera
- End to end machine learning method (from image frame to target location)
- Or non-linear transformation function

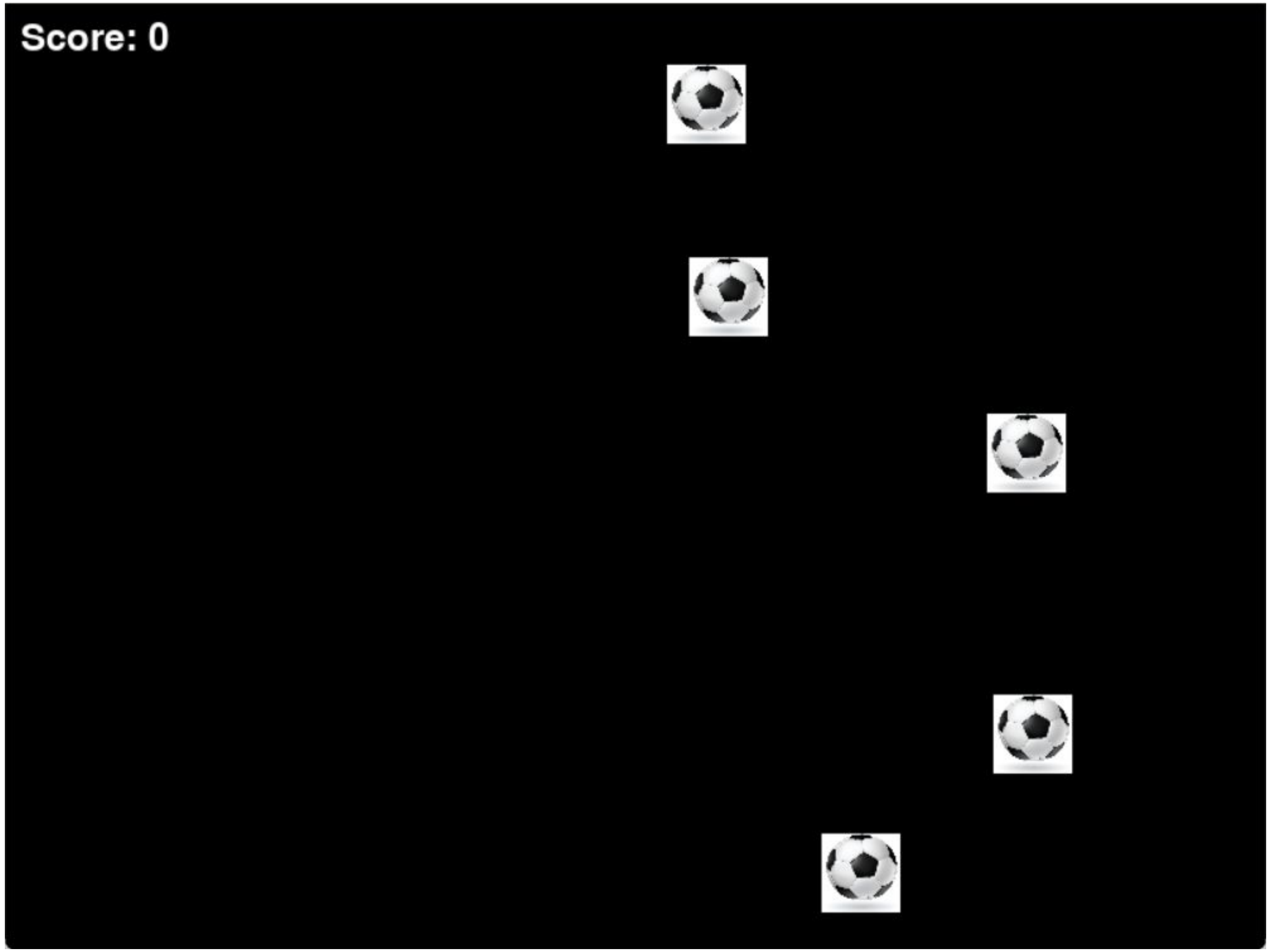
Virtual keyboard

1. Library: tkinter(small amount and fast enough)
2. The updated UI with simpler button layout and hover detection mechanism



Small game to test its accuracy

Library: pygame, numpy, sys



Brief technical highlights

1. A fully functional on-screen keyboard with keypress support and an editable text field.
2. Adjustable button sizes (width, height, font size) via sliders for customization.
3. A Text-to-Speech (TTS) feature using pyttsx3, which reads out the entered text aloud.
4. An interactive mouse tracking system to capture and display cursor coordinates in real-time.
5. Enhanced flexibility in the layout design and user experience:

   Wider first-row for important buttons (['←', 'Clear', 'Enter', 'Speak']).

   All other rows retain a consistent appearance.

   A linear(EMA) filter for the mouse movement to make better adaptation to gaze tracking.

Comparison with Commercial Product

Tobii Eye Tracker 5

- State-of-the-art
- Robust to head/face movement
- “Remote” (i.e., non-contact)
- $300 on Amazon

Our System

- Functional with some noise
- “Head-stabilized”
- Under $100

Other systems include non-remote (e.g., headsets, glasses), most more expensive than our system.

Tobii Eye Tracker Setup

Hands-free Typing & Text-to-Speech using Eye-Tracking

ELECTRICAL & COMPUTER ENGINEERING
UNIVERSITY OF MICHIGAN

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EECS 452: Digital Signal Processing Design Lab – Fall 2024

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Introduction

Many disabilities (e.g., facial or other muscle paralysis) affect people's ability to use electronic devices, specifically typing. Furthermore, those with facial paralysis often can't speak normally. By using eye-tracking to map eye movement onto a virtual keyboard, users will be able to type out words and sentences, hands-free, and then have it play back via text-to-speech.

Techniques

Pupil Detection: First, we use an open-source Python library called mediapipe [1] to do face landmark detection. These "facial landmarks" are pictured in Figure 2. They are produced by a pre-trained end-to-end neural network. We then select the facial landmarks corresponding to the pupil centers, i.e., two (x,y) pairs of coordinates in the camera image.
Calibration: We use a four-step calibration process that learns a perspective transformation to map the pupil centers to a cursor on the virtual keyboard (Figure 4).
Cursor Output: The perspective transform is applied to the camera feed to map the person's pupil positions to the virtual keyboard in real-time.
Text-to-Speech: Implemented with open-source Python library 'pyttsx3'.

System Setup

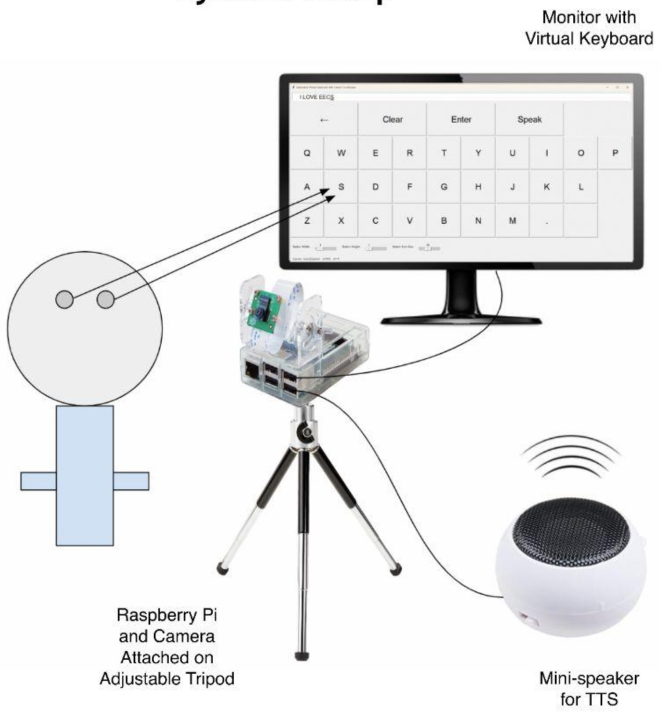
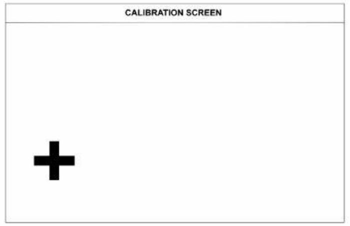


Fig 1: Final System Setup

Fig 2: Facial Landmarks from Mediapipe

Fig 3: Pupil Positions

Fig 4: Step 1/4 of Calibration



Results

With practice, it takes about 1 minute to type and speak "HELLO WORLD" (hence, 11 CPM). The cursor noise, although we significantly reduced it through filtering, is still present, which increases the typing time.

Conclusion / Future Improvements

Our system provides a relatively cheap (<$100) functional eye tracker, assuming no head or face movement, with some noise. Future improvements include using near-infrared light for better eye measurements, and a higher resolution / framerate camera for less noisy estimates. Also, more advanced (e.g., deep neural network / transformer) models for pupil -> cursor mapping.

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System Architecture