

Rider-Adaptive Automatic Bicycle Mirror

ECE 445 Project Proposal

Team 53

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1. Introduction

1.1 Problem

A bicycle mirror is useful only when it is pointed correctly for the person riding the bicycle. A mirror that works for one posture can become much less useful after the rider leans forward, sits upright, changes the seat height, or another rider uses the same bicycle. In each case, the rider's eye position moves, while the mirror stays at the same angle. The rider then has to stop and readjust the mirror by hand or turn farther away from the road ahead to check behind them.

Our project addresses that problem by automatically re-aiming the mirror after the rider changes position. The goal is not to replace normal traffic awareness or guarantee that every object behind the bicycle is visible. Instead, the system is designed to keep one chosen rear viewing region visible as the rider's eye position changes. Because the prototype is mounted on a bicycle, it also has to stay out of the way of the brake levers, steering motion, cables, and the rider's hands. The mechanical layout will use the bicycle requirements in 16 CFR Part 1512 as a safety reference when checking braking, protrusions, steering, and secure mounting [1].

1.2 Solution

The proposed system is a button-activated, two-axis automatic bicycle mirror. A Raspberry Pi Camera Module 3 Wide and an ST VL53L5CX-SATEL multizone Time-of-Flight (ToF/LiDAR) sensor will be mounted next to each other near the center of the handlebars. The camera will locate the rider's eyes in the image, while the VL53L5CX will provide an 8 x 8 depth map. We chose the Camera Module 3 Wide because its wide field of view gives the rider room to move without leaving the image, and we chose the VL53L5CX because its multizone measurement is much less likely to miss the rider than a single narrow LiDAR beam [2]-[4].

When the rider presses the adjustment button, the Raspberry Pi will collect five valid camera and depth frames. The eye midpoint in the camera image will be matched to the corresponding ToF zone, and the system will estimate the 3-D eye position using the camera calibration and measured depth. The camera and ToF sensor will be mounted with their optical centers within 30 mm of each other and calibrated together at several known rider distances so the image-to-depth mapping stays consistent.

$$X = (u - c_x) Z / f_x, \quad Y = (v - c_y) Z / f_y \quad (1)$$

In (1), u and v are the measured eye-midpoint pixel coordinates, c_x and c_y are the calibrated optical center, f_x and f_y are the calibrated focal lengths in pixels, and Z is the depth measured near the rider's face. The Raspberry Pi will send X , Y , Z , and a validity flag to the STM32G474RET6 over a 3.3 V UART link.

The STM32 will then calculate the mirror normal that bisects the direction from the mirror to the rider's eyes and the direction from the mirror to a fixed rear viewing target. Two small geared DC motors will control yaw and pitch. Two AS5600 magnetic angle sensors will measure the actual mirror angles so the controller can close the loop instead of estimating position from motor run time. After the mirror reaches its target, the motors stop. A secondary worm/friction-holding stage will keep the mirror from freely back-driving under bicycle vibration.

$$n = (e + r) / \|e + r\| \quad (2)$$

Equation (2) gives the target mirror-normal direction, where e is the unit vector from the mirror toward the rider's eye position and r is the unit vector from the mirror toward the fixed rear viewing target. The yaw and pitch commands are then calculated from n .

1.3 Visual Aid

Rider-Adaptive Automatic Bicycle Mirror - System Context

Button-triggered sensing and automatic re-aiming toward one fixed rear viewing region.

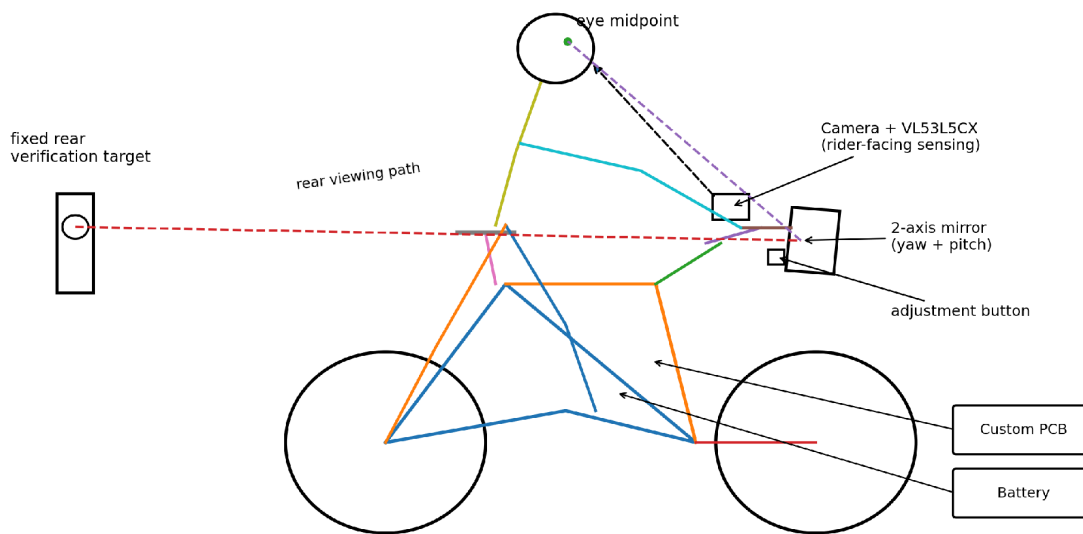


Figure 1. System-level view showing how the rider uses the automatic mirror. This is a usage diagram, not the electrical block diagram.

1.4 High-Level Requirements

The project will be considered successful if it meets all three of the following requirements:

- After the adjustment button is pressed, the system must detect the rider, calculate a new mirror position, and complete both-axis adjustment within 3.0 s. The final measured yaw and pitch angles must each settle within ± 1.0 degree of the calculated target.
- For three normal rider positions, including at least a 20 cm change in forward-backward head position, the system must automatically re-aim the mirror so that a fixed verification target located 3.0 m behind the bicycle is visible in at least 9 out of 10 trials at each rider position.
- The complete prototype must operate from its rechargeable battery for at least 60 min of powered testing, and the mounted hardware must remain secure through 20 full handlebar steering sweeps from stop to stop without contacting the brake controls, cables, or the rider.

2. Design

2.1 Block Diagram

Rider-Adaptive Automatic Bicycle Mirror - Detailed Block Diagram

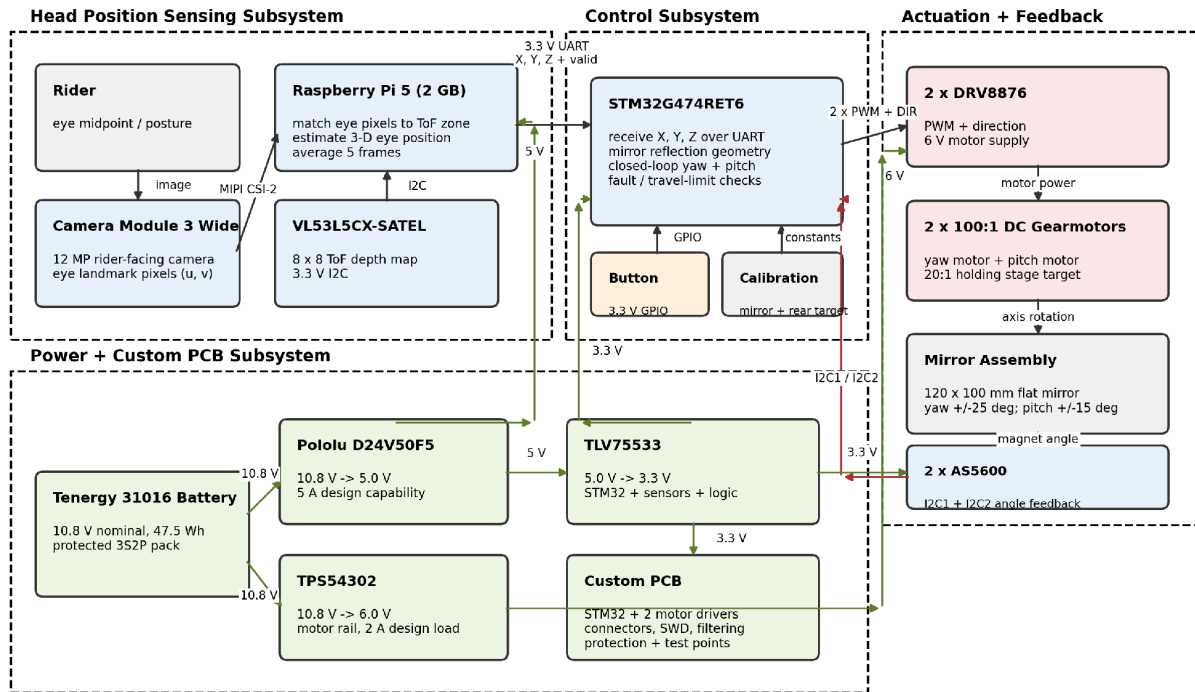


Figure 2. Detailed electrical, power, and data-flow block diagram. Supply voltages and data interfaces are labeled on the connections.

2.2 Mechanical Concept

Two-Axis Mirror Mount - Mechanical Concept (not to scale)

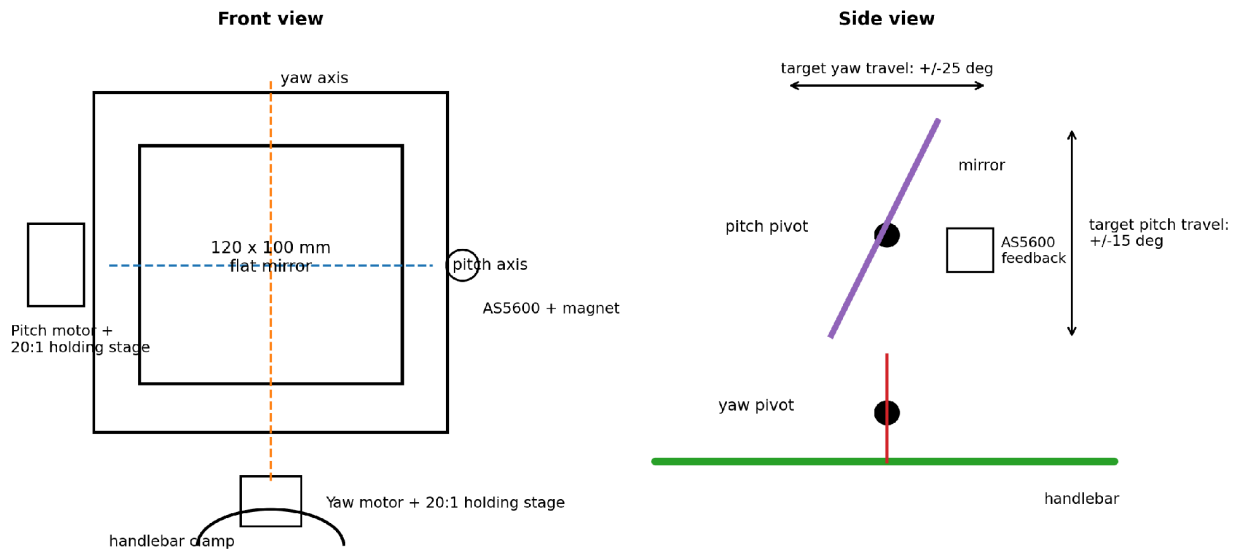


Figure 3. Mechanical concept for the two-axis mirror mount. The drawing shows the intended yaw and pitch axes, direct angle feedback, and the holding stage used after motor power is removed.

Each axis is measured directly by an AS5600. The 20:1 secondary holding stage is accepted only if the mirror passes the 60 s unpowered drift requirement, so the design does not assume the DC gearmotor will self-lock.

2.3 Subsystem Overview

2.3.1 Head Position Sensing Subsystem

This subsystem measures the rider's eye position at the moment the adjustment button is pressed. The Raspberry Pi Camera Module 3 Wide provides the image used for eye-landmark detection. The VL53L5CX-SATEL provides the depth measurement over an 8 x 8 grid, with ranging up to 4 m and a wide multizone field of view [2]-[4]. Instead of treating the face center as the final viewing point, the software will use the midpoint between the detected eyes whenever both eye landmarks are valid. This follows the geometry of the actual viewing point more directly.

The camera and ToF sensor are both connected to the Raspberry Pi 5. The camera uses MIPI CSI-2, while the ToF sensor uses I2C. After a button press, the Pi will collect five valid frames, reject obviously inconsistent depth zones, average the result, and send one X, Y, Z eye-position estimate to the STM32. This keeps the system from reacting to single-frame noise while still meeting the 3 s overall response requirement.

2.3.2 Controller and Mirror Geometry Subsystem

The STM32G474RET6 is the real-time controller for the mirror. It receives the eye position from the Raspberry Pi over 115200-baud, 3.3 V UART. The controller also stores the calibrated mirror location, the fixed rear-target location, yaw and pitch zero offsets, and the allowed mechanical travel. Using the reflection geometry in (2), the STM32 converts the eye position into yaw and pitch targets.

The STM32 also reads the adjustment button and performs all fail-safe checks. If the Pi reports an invalid measurement, the UART packet is incomplete, the requested angle is outside the allowed range, or either feedback sensor reports an invalid angle, the motors are disabled. This prevents a bad measurement from driving the mirror into a mechanical stop.

2.3.3 Motorized Mirror and Position Feedback Subsystem

The mirror will use two Pololu 100:1 Micro Metal Gearmotor MP 6 V motors, item #2367, one for yaw and one for pitch. At 6 V each motor is listed at 220 rpm no-load, 0.67 A theoretical stall current, and 0.94 kg-cm theoretical stall torque [5]. Each motor is driven by its own TI DRV8876 H-bridge. The DRV8876 accepts 3.3 V logic, supports a 4.5-37 V motor supply, and provides current regulation and fault protection [6].

Each mirror axis uses one AS5600 absolute magnetic angle sensor. The AS5600 uses the fixed I2C address 0x36, so the yaw and pitch sensors cannot share the same I2C bus without additional hardware. Our design therefore places them on separate STM32 I2C peripherals [7]. A magnet is coupled directly to each mirror axis so the measured angle represents the actual mirror position after the gear train. The target mirror is approximately 120 mm x 100 mm, with a yaw range of ± 25 degrees and a pitch range of ± 15 degrees.

The mechanical prototype will use a 20:1 secondary worm/friction-holding stage on each axis. The stage will be accepted only if, after the motors turn off, the mirror stays within 1 degree of its final angle for at least 60 s. This makes the holding behavior testable instead of assuming the DC gearmotor will self-lock.

2.3.4 Power and Custom PCB Subsystem

The system will use a protected Tenergy 31016 3S2P lithium-ion pack. The selected pack is 10.8 V nominal, 4400 mAh, about 47.5 Wh, and rated for 5.7 A continuous discharge [10]. A Pololu D24V50F5 regulator will generate the 5 V rail used by the Raspberry Pi 5. Raspberry Pi recommends a 5 V, 5 A supply for the Pi 5, and the D24V50F5 is designed for a typical continuous output of up to 5 A with adequate thermal conditions [8], [9].

The custom PCB will contain the STM32, two DRV8876 motor-driver circuits, the 6 V motor buck converter, the 3.3 V logic regulator, the two AS5600 interfaces, the button input, SWD programming, UART connection to the Raspberry Pi, connectors, test points, filtering, and protection. A TPS54302 buck converter will generate the 6 V motor rail from the battery; the device supports up to 3 A output [11]. The TLV75533 will generate 3.3 V logic from the regulated 5 V rail, not directly from the battery, because the TLV755 family has a 5.5 V maximum input [12].

2.4 Subsystem Requirements

The requirements below are written as testable subsystem behavior rather than simply repeating off-the-shelf component specifications.

Head Position Sensing

- The camera and ToF optical centers must be mounted within 30 mm of each other and calibrated together at 0.5 m, 0.8 m, and 1.1 m before system testing.
- The sensing subsystem must detect both eye landmarks and produce a valid eye midpoint in at least 9 of 10 button-triggered trials for a forward-facing rider between 0.4 m and 1.2 m from the sensor assembly.
- Across the calibrated rider range, the estimated eye position must stay within 20 mm transverse error and 30 mm depth error at the three calibration/check positions used for validation.
- The Raspberry Pi must average five valid frames and deliver X, Y, Z, and a validity flag to the STM32 within 0.8 s of the button press.

Controller and Geometry

- The Raspberry Pi-to-STM32 message must use 3.3 V UART at 115200 baud and include a validity field plus all three position coordinates in a fixed packet format.
- The STM32 must reject any command outside the calibrated rider range or outside the mirror travel limits of ± 25 degrees yaw and ± 15 degrees pitch.
- The mirror-geometry calculation and target-angle update must complete within 50 ms after a valid UART packet is received.
- Any invalid sensing result, UART timeout, feedback-sensor fault, or travel-limit violation must disable both motor outputs within 100 ms.

Motorized Mirror and Feedback

- The yaw and pitch feedback channels must update at a minimum of 50 Hz and provide angle resolution finer than 0.5 degree over the required travel range.
- After a valid target is issued, each axis must settle within ± 1.0 degree of the commanded angle without sustained hunting, and the complete two-axis adjustment must finish within 2.0 s.
- After motor power is removed, the mirror must drift by less than 1.0 degree on either axis over a 60 s stationary hold test.
- The motor-control software must enforce the mechanical travel limits even if a target command would otherwise request a larger angle.

Power and PCB

- The 5 V Raspberry Pi rail must remain between 4.90 V and 5.10 V during sensing and motor operation and must have 5 A design capability.
- The 6 V motor rail must remain between 5.7 V and 6.3 V and support at least 2.0 A combined peak load without resetting the STM32 or Raspberry Pi.
- The 3.3 V logic rail must remain within $\pm 5\%$ while powering the STM32, angle sensors, button input, and logic interfaces.
- The PCB must include input protection, local decoupling, accessible ground/5 V/6 V/3.3 V test points, SWD access, and a hardware path for disabling both motor drivers.

2.5 Tolerance Analysis

The largest technical risk is whether the combined sensing error and mirror-angle error are small enough that the fixed rear target is still inside the mirror's usable field of view. The first part of the error comes from estimating the rider's eye position. Using a nominal eye-to-mirror distance of 0.65 m and the subsystem target of 20 mm transverse position error, the angular eye-direction error is

$$\theta_{eye} = \text{atan}(0.020 / 0.65) = 1.76 \text{ degrees} \quad (3)$$

The second error comes from the mirror itself. A flat mirror rotates the reflected ray by approximately twice the mirror-angle error. With the closed-loop requirement of ± 1.0 degree, the reflected-ray error caused by the actuator can be as large as 2.0 degrees. A conservative worst-case directional error is therefore

$$\theta_{total} = 1.76 \text{ degrees} + 2(1.0 \text{ degree}) = 3.76 \text{ degrees} \quad (4)$$

At the 3.0 m rear verification distance, 3.76 degrees corresponds to a lateral sight-line shift of

$$\Delta = 3.0 \tan(3.76 \text{ degrees}) = 0.197 \text{ m} \quad (5)$$

The proposed flat mirror is approximately 120 mm wide by 100 mm tall. At a 0.65 m eye-to-mirror distance, its half-angle is approximately 5.27 degrees horizontally and 4.40 degrees vertically. Both values are larger than the 3.76 degree worst-case error estimate. This gives a small but usable margin and shows that the combination of a 20 mm sensing target, 1 degree closed-loop mirror accuracy, and a 120 x 100 mm mirror is feasible for the 3 m verification test. During final testing we will record the actual sensing error and mirror settling error and compare them against this analysis.

2.6 Selected Components

The hardware below is the selected baseline for the prototype. The choices favor parts that are small, available, reasonably priced, and straightforward to integrate with the rest of the system.

Function	Selected part	Why it fits
Vision computer	Raspberry Pi 5, 2 GB	Enough CPU headroom for button-triggered eye-landmark detection and sensor fusion.
Rider camera	Raspberry Pi Camera Module 3 Wide	Wide 120-degree diagonal field of view gives more tolerance to rider motion [2].

Function	Selected part	Why it fits
Depth / LiDAR	ST VL53L5CX-SATEL	8 x 8 multizone ToF, up to 4 m; avoids the miss problem of a single-point beam [3], [4].
Mirror motors	2 x Pololu #2367 100:1 MP 6 V	Small 10 x 12 mm gearbox and enough torque for a compact mirror mechanism [5].
Motor drivers	2 x TI DRV8876	Bidirectional brushed-DC control, 3.3 V logic, current regulation, and protection [6].
Angle feedback	2 x AS5600	Absolute magnetic angle sensing directly on each mirror axis [7].
Battery	Tenergy 31016	Protected 47.5 Wh pack with enough continuous-discharge capability for Pi + motors [10].
Pi regulator	Pololu D24V50F5	5 V / 5 A class regulator from the 3S battery [9].

The selected VL53L5CX-SATEL is about \$21, the Pololu motors are \$23.95 each, the Tenergy battery is \$76.99, and the 5 V Pololu regulator is \$32.95 at current manufacturer/vendor listings. Those prices keep the sensing and actuation hardware in a reasonable range for an ECE 445 prototype [4], [5], [9], [10].

3. Ethics, Safety, Societal Impact, and Standards

3.1 Ethical Considerations

The main ethical concerns are rider safety, privacy, and making realistic claims about what the system can do. The IEEE Code of Ethics emphasizes public safety, privacy, and honest technical claims, while the ACM Code of Ethics emphasizes avoiding harm, respecting privacy, and evaluating risks [13], [14]. These points matter directly for this project because a rider could rely on the mirror during traffic checks.

The camera is used only to estimate eye geometry after the rider presses the button. The prototype does not need to identify the rider, recognize a person by name, or store face images. Image processing will be performed locally on the Raspberry Pi, and the software will not intentionally save or transmit the camera frames. We will also report actual test results rather than implying that the mirror can replace normal rearward checks or guarantee that every vehicle is visible.

3.2 Safety and Standards

The main mechanical safety concern is adding moving hardware to the handlebars. The sensor assembly, button, wiring, and mirror mount will be positioned so they do not block brake levers, control cables, the rider's hands, or the full steering range. Wiring will use strain relief, exposed edges will be covered or rounded, and the mirror mechanism will include both software and physical travel limits. We will perform initial testing with the bicycle stationary before any moving test. 16 CFR Part 1512 is used as a safety reference for braking, protrusions, steering, and secure bicycle hardware [1].

The VL53L5CX uses an infrared laser emitter, but ST specifies the device as a Class 1 laser product when used in its intended configuration under IEC 60825-1:2014. We will not modify the optical emitter or add optics that focus the beam [3]. The lithium-ion battery is a protected commercial pack and will be charged only with a compatible charger. During soldering, rework, and battery testing, the team will follow ECE 445 lab safety practices, including eye protection, controlled hot-air/soldering use, insulated battery leads, and checking power rails for shorts before connecting the battery.

The software is also designed to fail safely. If the rider is not detected, the ToF depth is invalid, the UART packet times out, an angle sensor returns an invalid value, or a travel limit is reached, both motor drivers are disabled. The mirror then stays in its current position instead of continuing to move on bad data.

3.3 Societal, Economic, and Environmental Impact

The main benefit of the project is convenience and more consistent rearward visibility when a rider changes posture or when a bicycle is shared. It may also be useful in adaptive cycling situations where repeated manual mirror adjustment is difficult. At the same time, the electronics make the system more expensive and more complicated than a normal bicycle mirror, so the automatic adjustment only makes sense if it is reliable enough to justify that added complexity.

The prototype uses commonly available commercial parts instead of custom optics, which keeps the design realistic for a senior-design build. The largest individual purchased items are the battery, Raspberry Pi, camera, and power regulator, while the ToF sensor itself is about \$21. The environmental impact mainly comes from the lithium-ion battery, PCB, motors, and eventual electronic waste. To reduce unnecessary waste, the design keeps the sensing module, PCB, battery, and mirror mechanism replaceable as separate assemblies rather than requiring the entire system to be discarded if one part fails.

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