ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Particle Image Velocimetry

Team #8

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1 Introduction

1.1 Problem

Understanding how fluids move is crucial for many scientific and engineering applications. However, traditional methods to visualize fluid flow are complicated and not easy for everyone to grasp. We need a simple and accessible solution for visualizing fluid dynamics. We need to design a device that can demonstrate particle image velocimetry. The device can demonstrate in a simple way that children can easily understand and interact with. Low cost, easy maintenance, durable.

1.2 Solution

- The proposed Fluid Velocity Measurement System is a comprehensive solution comprising distinct subsystems for accurate and real-time measurements. Within the system, the Fluid Channel Subsystem ensures continuous fluid circulation through a sophisticated piping system driven by manually operated pumps.
- The Laser and Optical Subsystem incorporates an adjustable laser source and optical components, such as lenses and mirrors, to illuminate and capture clear images of particles within the fluid.
- The Particle Injection Subsystem generates and evenly disperses trackable particles for enhanced visibility.
- The Image Acquisition Subsystem, equipped with a digital camera, captures and aligns particle images, forwarding them to an Image Processing System for precise velocity calculations.
- The Remote Access and Control Subsystem allows an instructor to control the device remotely with a simple application.
- The hands-free Voice Control Subsystem allows children to interact with the device safely and conveniently.
- The User Interface and Data Visualization Subsystem offers a user-friendly platform with a display for real-time fluid images and velocity field visualizations, enabling efficient monitoring and analysis of fluid dynamics.
- This holistic solution caters to applications demanding accurate and timely fluid velocity information without duplicating details from the specified components.
- Our PIV device also can provide some fun parts to help them understand how it works and rise their interests in fluid dynamics.

1.3 Visual Aid

See Figure 1

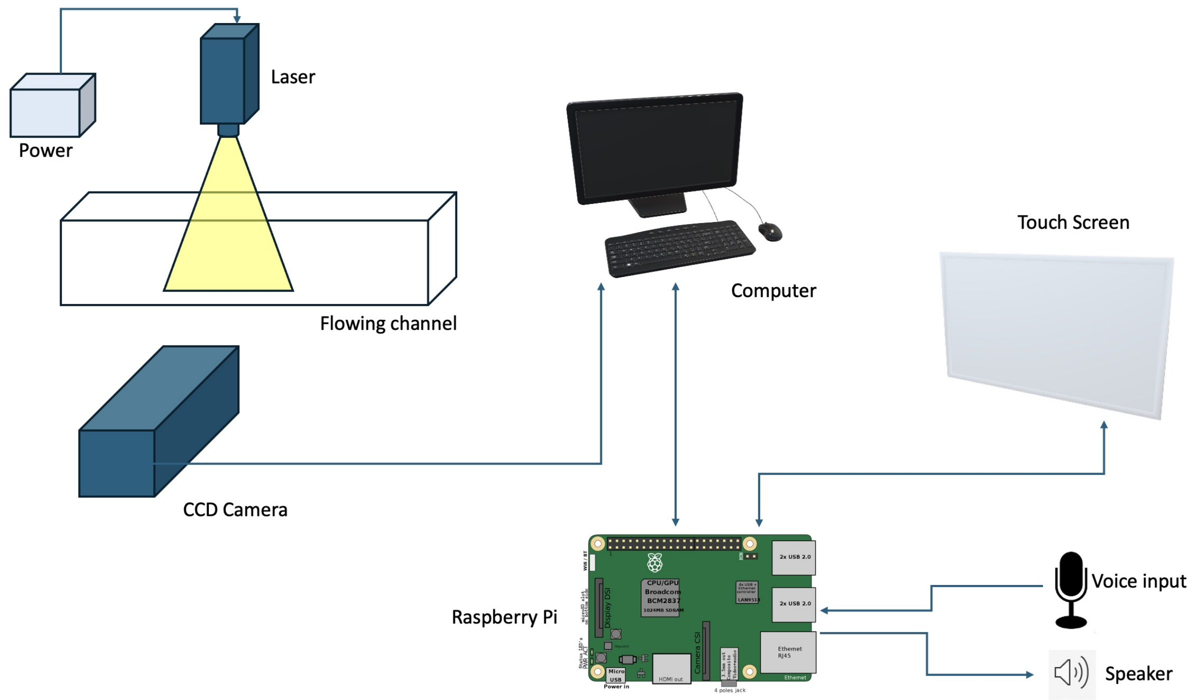

Figure 1: Visual Aid

1.4 High-level requirements list

- The system should accurately estimate the fluid velocity in the correct order of magnitude.
- The system should offer an interactive experience with a user-friendly interface that includes real-time visualizations, e.g., particle images, particle velocities, and calculated flow rate of fluids.
- The user should be able to control the PIV demonstration (e.g. start/terminate the measurement, change the flow rate of fluids) in real time via GUI and input devices like keyboard or voice control. The system should also feature a more than 50 percent accurate voice control for hands-free operation, ensuring it is safe and accessible for educational use.

2 Design

2.1 Block Diagram

See Figure 2

2.2 Subsystem Overview

- Flowing System: This is a device that measures and controls the flow rate of fluids and is directly connected to the Particle Injection System by a mechanical structure.In the system, the pump should be able to supply the water with a velocity of 5-15cm/s.
- Particle Injection System: The Particle Generator, which produces small, brightly colored particles that can be tracked in the fluid, is directly connected to the Flowing System by a mechanical structure.
- Illumination System: The illumination system consists of a laser source with adjustable position and a complete set of devices for generating a clear spot and image. Adjustments are made via computerized feedback with the Image Acquisition System.
- Image Acquisition System: The camera captures an image of the particles in the fluid and calculates the velocity of the particles. It is connected to the Illumination System via a computer and feeds back to each other.
- Remote Access and Control System: A Raspberry Pi with Internet connection communicates with a remote server, which receives commands from users. It enables remote control of the operating system and mechanical components of the PIV.
- Voice Control System: This is a voice-controlled interface which enables our PIV to understand and respond to simple verbal instructions and answer simple questions from users. The voice input comes from an audio module connected to a Raspberry Pi. Audio response generated from the remote server is played on a mini speaker connected to the audio module.
- Interactive User Interface: A graphical user interface (GUI) implemented on the Raspberry Pi, allowing users to control various aspects of the PIV system with a cursor, view real-time data, and adjust settings as needed.
- Data Visualization System: A 3.5-inch screen displays our data visualization generated by the Raspberry Pi. This interface will enable users to visualize the velocity of particles within the fluid in real time, providing an intuitive and interactive way to understand complex fluid dynamics.

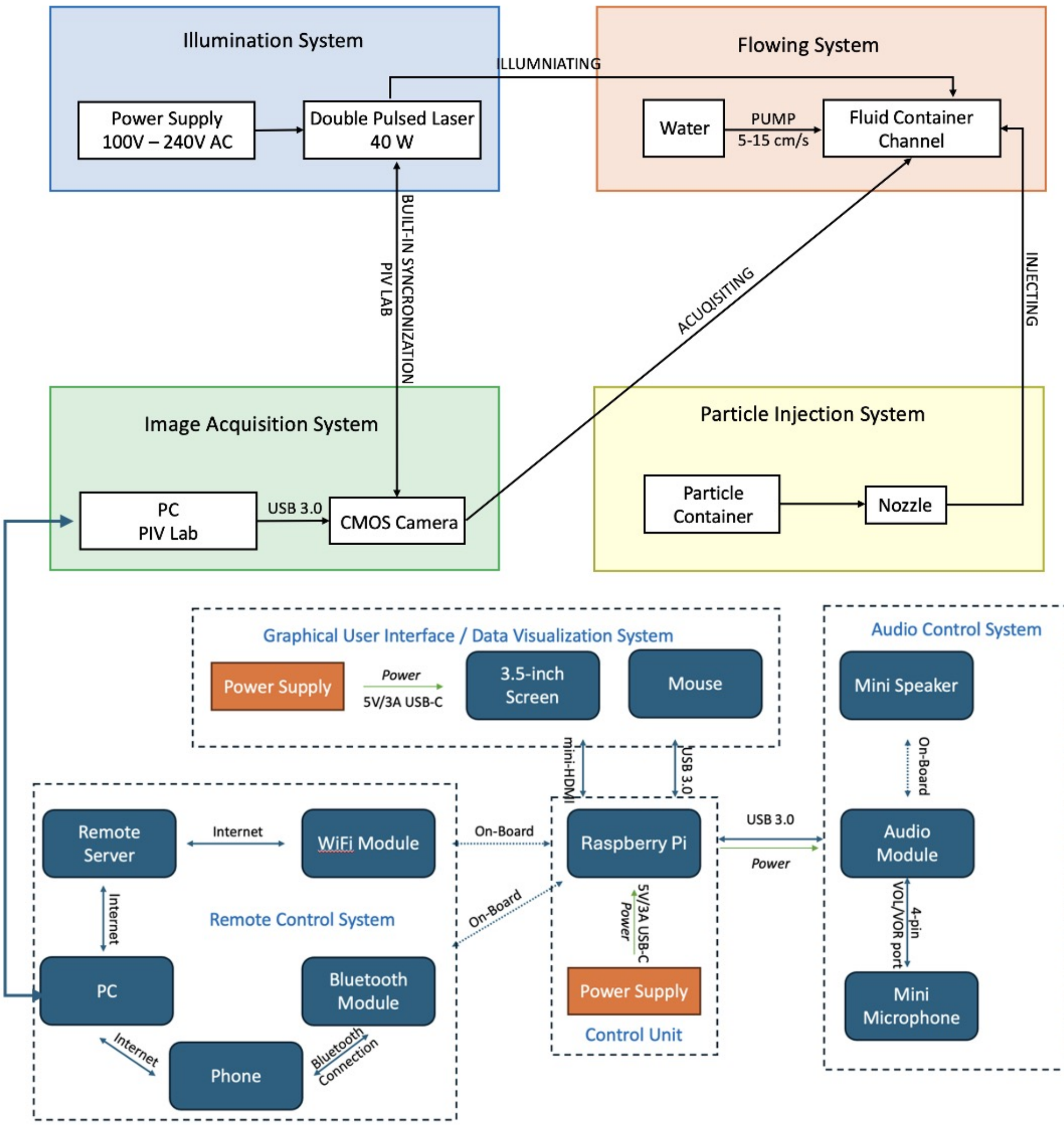

Figure 2: Block Diagram

2.3 Subsystem Requirements

- Flowing System: Transparent container that allows fluid flow through. There are small manually operated pumps that ensure that the fluid circulates through the channel. We can measure and control flow rate of the fluid.The Flowing System and the Particle Injection System are mechanically linked. The Flowing System must ensure that the liquid flow is not disturbed by the particles generated by the Particle Injection System.In the system, the pump should be able to supply the water with a velocity of 5-15cm/s.
- Particle Injection System: A particle generator produces small particles that can be followed in a fluid, such as brightly colored markers. The particle injector introduces particles into the fluid channel, ensuring that they are evenly distributed and can be illuminated by the laser.The Flowing System and the Particle Injection System are mechanically linked. The Flowing System must ensure that the liquid flow is not disturbed by the particles generated by the Particle Injection System.The particles emitted should have these requirements: (1) the specific gravity should be as consistent as possible with the experimental fluid; (3) the shape should be as round as possible and the size distribution should be as uniform as possible; and (4) there should be a sufficiently high light scattering efficiency.
- Illumination System: A laser source that provides a laser beam for illuminating particles in the fluid and ensures that the laser source is position adjustable. And contains an optical system including lenses, mirrors, and filters for creating a clear spot and image. The double pulsed laser needs a power of 40W and the power supply for the illumination system should be a 100V-240V AC.
- Image Acquisition System: A camera is used to capture images of the particles in the fluid, sending the captured pictures to an image processing system, which, is used to calculate the particle velocity. At the same time the camera makes sure to align the particles in the fluid channel. The camera should have high spatial resolution, high sensitivity, short and accurate inter-frame time, and sometimes high frame rates.The camera and computer are connected via a USB port, requiring a USB cable capable of stable signal transmission.The camera needs to be able to take two consecutive images of particles at intervals of less than 100 microseconds.
- Remote Access and Control System: The system should maintain a stable and secure connection with a latency of no more than 200 milliseconds to the remote server over the Internet or a local network. Should reconnect within 5 seconds after disconnection. It should automatically reconnect if the connection is lost. The server should ensure that only authorized users can send commands to the system, with support for multiple user roles and permissions. The server should provide real-time status feedback of the mechanical components to the remote server, allowing users to verify that commands have been executed correctly.
- Voice Control System: The system should accurately translate voice commands into actionable tasks or queries that the PIV system can execute or answer. It should

interpret voice commands from users in real-time (with a ¡ 5 s latency). The system should generate audio responses to voice commands, including confirmations of actions taken or providing requested information, and play these through the connected mini speaker.

- Interactive User Interface: The GUI should ensure that users can find functions within 3 clicks or less. It should respond to user inputs and reflect changes in the system within 100 ms. The GUI should load within 10 seconds upon startup and respond to user interactions within 500 ms.
- Data Visualization System: The system should be able to update visualizations to reflect real-time data with a maximum delay of 200 ms. The system must enable users with little technical background to interpret data correctly, providing contextual help where necessary.

2.4 Tolerance Analysis

The velocity is calculated by the following formula:

$$V = \frac{\Delta X}{\Delta t}$$

$$\Delta X = \frac{D_p A}{R}$$

where Δt is the time interval between successive images. D_p is the average displacement of particles between successive images, measured in pixels; A is the size of the area being imaged; R is the resolution of the digital camera, measured in pixels.

The main error may come from the following sources: 1. Error in Δt. We require the digital camera to take successive photos in a short time. If it happens to have a delay in taking photos, the actual Δt will be different from the expected one. 2. Error in ΔX. This error includes errors in measuring the displacement between the particles (D_p) and the error in measuring the size of the imaged area (A).

From the above analysis, we see that the main error source is the time interval Δt. When Δt is very small, a tiny error in Δt will cause a large influence on the system.

3 Ethics and Safety

In this project, we consider following ethics and safety concerns:

- Safety. The IEEE[1] code emphasizes the importance of prioritizing safety and health in engineering project, ”to hold paramount the safety, health, and welfare of the public.” This is strongly relevant to the safety of the Laser and Optical Subsystem and the Particle Injection Subsystem in this project. Specifically, we will ensure the Laser not causing any potential harm to the users. Especially when demonstrating PIV to children, we need to keep the Optical Subsystem safe from children's possible actions. One possible solution is to add a safety system to our finished product. When the whole system faces risks of causing harm, we force the entire system to shut down.
- Privacy. The IEEE and ACM[2] codes also require engineers to respect the public's privacy. Since our design includes a voice control system, we need to ensure that the information we obtain will not be disclosed for other uses.
- Educational impact. Since our project will be applied to education, especially to demonstrate PIV to children, we need to ensure the system has a positive educational impact, reducing confusion and avoiding any harm to the users. For this reason, we plan to create materials that explain the principles of the PIV measurement and operation mannual of the control system in an age-appropriate manner.

References

[1] IEEE. “”IEEE Code of Ethics”.” (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 03/06/2024).
[2] ACM. “”ACM Code of Ethics”.” (2018), [Online]. Available: https://www.acm.org/code-of-ethics (visited on 03/06/2024).