

ABSTRAK

Septia Dewi Fatimah. 220481100017. Rancang Bangun Instrumentasi *Wind Tunnel* dan *Heating Ventilation Air Conditioning* (HVAC) Kecepatan, Tekanan dan Temperatur (*Airsped, Barometer, Themperature*). Program Studi S1 Teknik Mesin, Jurusan Teknik Industri dan Mesin, Fakultas Teknik, Universitas Trunodjoyo Madura. 2026.

Penelitian ini bertujuan merancang dan membangun sistem instrumentasi alat ukur kecepatan udara (*airspeed*), tekanan barometrik, dan temperatur udara yang terintegrasi pada *wind tunnel* Laboratorium Program Studi Teknik Mesin Universitas Trunodjoyo Madura, guna menyelesaikan permasalahan ketidaktersediaan sistem perekaman data yang mampu mengukur ketiga variabel tersebut secara simultan. Permasalahan mendesak yang melatarbelakangi penelitian ini adalah penggunaan anemometer komersial UT363 berpenampang 160×50 mm pada *test section* berpenampang 350×350 mm yang menghasilkan *blockage ratio* sebesar 6,5% melampaui batas toleransi standar aerodinamika sehingga berpotensi mengganggu profil aliran udara dan menurunkan akurasi pengujian secara sistematis.

Penelitian dilaksanakan melalui empat tahapan: perancangan probe *pitot-static* silindris berdiameter 10 mm dan panjang 70 mm yang difabrikasi menggunakan teknologi cetak tiga dimensi FDM dengan material PLA mengacu standar ISO 3966:2008; pemilihan sensor tekanan diferensial MPXV7002DP dan sensor barometer-temperatur BMP388 berdasarkan evaluasi tujuh kriteria teknis; pengembangan model estimasi kecepatan udara berbasis persamaan Bernoulli dengan koreksi densitas udara *real-time* menggunakan persamaan $v = \sqrt{(128,38 \times \Delta P \times T_K / P_B)}$; serta integrasi seluruh subsistem pada dua modul mikrokontroler ESP32-C3 Supermini yang berkomunikasi secara nirkabel melalui protokol ESP-NOW. Data hasil pengukuran ditampilkan pada layar LCD TFT ILI9341 2,8 inci dan disimpan dalam format CSV. Validasi kinerja dilakukan terhadap 20 data pengujian menggunakan uji normalitas *Kolmogorov-Smirnov*, *One Sample T-Test*, dan *Wilcoxon Signed Rank Test* pada taraf signifikansi $\alpha = 0,05$.

Hasil pengujian menunjukkan bahwa probe yang dirancang berhasil mereduksi *blockage ratio* dari 6,5% menjadi 0,57% penurunan sebesar 91,2% dibandingkan anemometer UT363. Estimasi kecepatan udara pada posisi *downstream* menghasilkan $R^2 = 0,9765$ dan RMSE = 0,7463 m/s, dengan uji T-Test menghasilkan p-value = 0,154 > 0,05 sehingga tidak terdapat perbedaan signifikan antara alat ukur yang dibangun dan anemometer referensi. Estimasi temperatur menghasilkan $R^2 = 0,935$ dengan bias sistematis +0,64°C, sedangkan estimasi tekanan barometrik menunjukkan linearitas sangat baik dengan nilai *slope* = 0,999 dan bias -0,68 hPa keduanya memiliki dampak terhadap *error* estimasi kecepatan di bawah 0,12%. Total realisasi biaya pembangunan alat sebesar Rp 658.000, lebih rendah 49% dari rencana anggaran biaya yang ditetapkan sebesar Rp 1.290.000.

Kata kunci: *wind tunnel*, instrumentasi, *airspeed*, sensor tekanan, ESP32, HVAC, anemometer.

ABSTRACT

Septia Dewi Fatimah. 220481100017. *Design and Construction of Wind Tunnel and Heating Ventilation Air Conditioning (HVAC) Instrumentation for Speed, Pressure, and Temperature (Airspeed, Barometer, Temperature). Undergraduate Program in Mechanical Engineering, Department of Industrial and Mechanical Engineering, Faculty of Engineering, Trunodjoyo University, Madura. 2026.*

This research aims to design and build an instrumentation system for measuring airspeed, barometric pressure, and air temperature integrated in the wind tunnel of the Mechanical Engineering Study Program Laboratory, Trunodjoyo University, Madura, in order to solve the problem of the unavailability of a data recording system capable of measuring these three variables simultaneously. The pressing problem behind this research is the use of a commercial UT363 anemometer with a cross section of 160×50 mm on a test section with a cross section of 350×350 mm which produces a blockage ratio of 6.5% exceeding the standard aerodynamic tolerance limit thus potentially disrupting the airflow profile and reducing the test accuracy systematically.

The research was carried out through four stages: the design of a cylindrical pitot-static probe with a diameter of 10 mm and a length of 70 mm fabricated using FDM three-dimensional printing technology with PLA material referring to the ISO 3966:2008 standard; the selection of the MPXV7002DP differential pressure sensor and the BMP388 barometer-temperature sensor based on the evaluation of seven technical criteria; the development of an airspeed estimation model based on the Bernoulli equation with real-time air density correction using the equation $v = \sqrt{(128.38 \times \Delta P \times T_K / P_B)}$; and the integration of all subsystems on two ESP32-C3 Supermini microcontroller modules that communicate wirelessly via the ESP-NOW protocol. The measurement data is displayed on a 2.8-inch ILI9341 TFT LCD screen and in CSV format. Performance validation was performed on 20 test data using the Kolmogorov-Smirnov normality test, One Sample T-Test, and Wilcoxon Signed Rank Test at a significance level of $\alpha = 0.05$.

The test results showed that the designed probe successfully reduced the blockage ratio from 6.5% to 0.57% a 91.2% reduction compared to the UT363 anemometer. The air velocity estimation at the downstream position produced $R^2 = 0.9765$ and RMSE = 0.7463 m/s, with the T-Test producing a $p\text{-value} = 0.154 > 0.05$ so that there was no significant difference between the built measuring instrument and the reference anemometer. The temperature estimation produced $R^2 = 0.935$ with a systematic bias of $+0.64^\circ\text{C}$, while the barometric pressure estimation showed very good linearity with a slope value = 0.999 and a bias of

−0.68 hPa both of which had an impact on the velocity estimation error below 0.12%. The total realized cost of building the tool was Rp 658,000, 49% lower than the planned budget of Rp 1,290,000.

Keywords: *wind tunnel, instrumentation, airspeed, pressure sensor, ESP32, HVAC, anemometer.*