DOI 10.5162/SMSI2025/D3.4

Power control and app connection via Bluetooth for NDIR-Sensor-applications

Moritz Ueberschär, Manuel Jung, Falk Liebold
Cooperative University Gera-Eisenach; Department of Technology;
Electrical and electronic Engineering; Weg der Freundschaft 4, 07546 Germany
falk.liebold@dhge.de

Summary:
For NDIR gas analysis, a constant emission spectrum of the integrated IR emitter is necessary. This requires the supply of constant electrical power. An electronic circuit is designed that enables the power implemented at the emitter to be set and measured. A digital controller with dynamic parameter determination is implemented in a microcontroller. A mobile smartphone application is created to display measured values and set the reference variable. Bluetooth communication enables cyclic data exchange between the app and the microcontroller.

Keywords:
Infrared emitter, digital power control, microcontroller, smartphone app, Bluetooth communication

Infrared emitter

One method in the field of gas sensing is non-dispersive infrared gas analysis (NDIR gas analysis).[1] Infrared emitters are used whose emission spectrum depends on the electrical power supplied.[2] It is therefore important for the measurement process to keep this power constant. Due to a non-linear relationship between the emitter temperature resulting from a certain emitter power and the resulting spectral energy density in the range of the wavelength used for analysis, even small power fluctuations cause a significant measurement error in NDIR gas measurement.[3]

Circuit design

A transistor serves as the power control actuator, which is controlled by a 32-bit microcontroller using the pulse width modulation method. A current regulator defines the operating range of the actuator and decouples it from the supply voltage. A smoothing capacitor generates a DC voltage from the PWM voltage and creates a quantifiable time constant for the dynamic transmission behavior of the circuit. The power measurement is carried out indirectly via two differential amplifier circuits for measuring current and voltage. The current is measured via a measuring resistor and the voltage is measured directly across the electrical load. A parallel resistor optimizes the adjustment range with regard to optimal utilization of the available PWM range to the specified working range and thereby maximizes the effectively usable resolution.

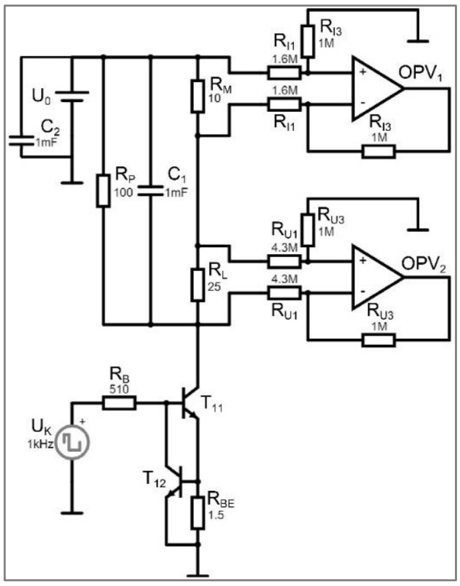

Fig. 1 Circuit Design

Controller

The electrical circuit of the power control can be described mathematically within the working area by the following relationship:

$$P_{RL}(s) = \frac{{I_{max}}^2}{1 + s \cdot T_1} \cdot \left(\frac{R_P}{R_L + R_M + R_P}\right)^2 \cdot R_L \cdot K(s)^2$$

[1] cf. [Wie22] pp. 393 f.
[2] cf. [MH24b] p. 3
[3] cf. [Wie22] pp. 1219-1221, [INS21] p. 2

$$T_1 = \frac{R_P}{R_P + R_M + R_L} \cdot (R_M + R_L) \cdot C_1$$

The squared influence of the duty cycle K(s) of the PWM voltage represents a static non-linearity. This is linearized by implementing a square root function as an inverse non-linearity in the microcontroller. The measured values of current and voltage are denoised in the microcontroller using a digital filter in the form of a T_1 element. The T_1 element has a limit frequency of $\omega_0 = 200\ s^{-1}$ and thus generates a delay element with $T_2 = 5$ ms. Overall, this results in a PT_2 controlled system with the following transfer function:

$$G_S = \frac{K_{PS1}}{(1 + sT_1) \cdot (1 + sT_2)}$$

$$K_{PS1} = \left(\frac{R_P}{R_L + R_M + R_P}\right)^2 \cdot R_L \cdot I_{max}{}^2$$

Closed loop control

The following figure shows the control loop consisting of the controller G_R and the controlled system.

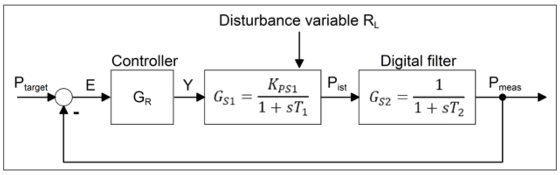

Fig 2 Digital control loop

A PI controller is used to control the PT_2 system, the parameters of which are determined using the method of compensating the largest system time constant[4]:

$$T_n = T_1$$

$$K_{PR} = \frac{T_1}{2 \cdot K_{PS1} \cdot T_2}$$

The resistor R_L represents a disturbance variable that can be determined from the current measured values for current and voltage measurement. In order to achieve a homogeneous response behavior over the entire working range of the control, the current resistance value is used to determine the controller parameters during the microcontroller's runtime from the context of the mathematical system model and thus dynamically adapt them.

Program structure of the microcontroller

In order to optimally use the microcontroller's computing power, the program is divided according to the different time requirements of individual functions, see the following figure.

[4]cf. [Zac22] S. 21

Bluetooth communication works with a cycle time of 100 ms, as this has the lowest real-time requirement and the graph in the app is also displayed at a 0.1 Hz rate.

The cycle time of the controller was selected to be sufficiently short at 0.5 ms with system time constants of T_1=16.7…47.4 ms and T_2=5 ms in order to achieve a quasi-continuous behavior of the control loop.

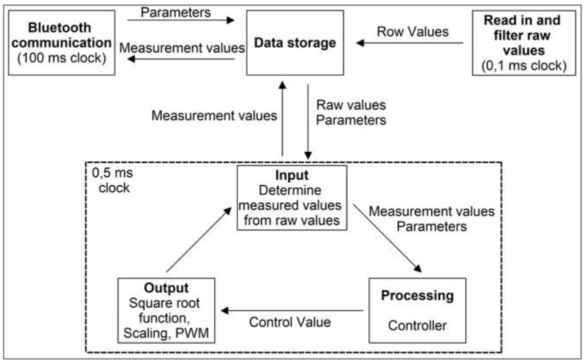

Fig 3 Program structure

The raw values of the current and voltage measurement are read and filtered in a cycle of 0.1 ms. This oversampling, in conjunction with the digital T_1 element, improves the quality of the measurement signals through reduced noise behavior.

The different cycle times are implemented using function calls in the interrupt service routines of various cyclic timer interrupts.

Smartphone application

The smartphone app enables communication between the user and the circuit via Bluetooth with the microcontroller. The target power value can be set using a slider or a text field. The current performance value is displayed in another text field. In addition, current, voltage, resistance and power curves are displayed in a graph.

Bluetooth data exchange

The data is transmitted cyclically as a character string. Semicolons are used to separate the individual pieces of information. The data sent from the microcontroller to the app contains the current measurements of current, voltage, resistance and power of the IR emitter. The data sent by the app to the microcontroller contains the setpoint of the control, controller parameters Kp and Tn, as well as the operating mode of the controller.

DOI 10.5162/SMSI2025/D3.4

Results

When testing the system, it was shown that the power of the electrical load can be controlled within the assigned working range. The measured value display in the app shows that the actual value follows the target value quickly and fluctuates around the target value with a deviation of 1 mW. The control behavior is examined using step responses and corresponds to expectations. Fig 4 shows the behavior based on a sudden change in resistance from 19 ohms to 80 ohms at 500 mW.

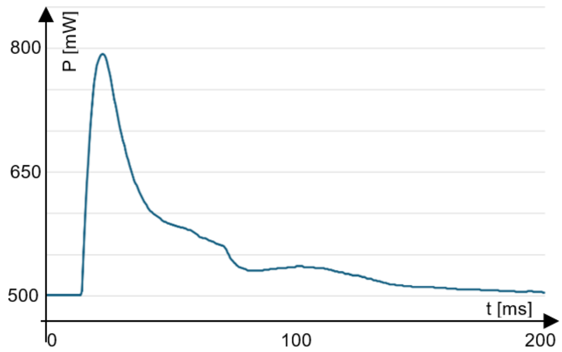

Fig 4 Control loop reaction to a disturbance

The transmission and display of the measured values in the mobile application works without interruption and has no noticeable delay. This means that the operator can use the app to monitor the current status of the circuit through the time curves displayed. The specification of the setpoint and the selection of the operating mode of the controller including parameter input works as expected.

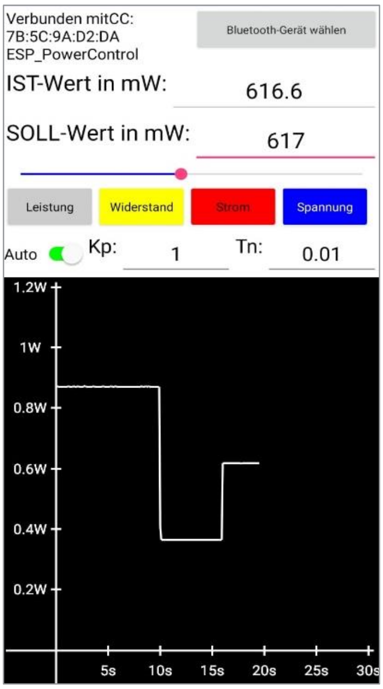

Fig 5 Mobile application

Conclusion

A digital power control of an electrical load was successfully implemented and visualized via an app. The implementation developed represents a prototype that fulfills the required functionality. Future developments can build on this.

References

[INS21] Infrasolid: "WHITE PAPER The Art of fastest Precision“, Infrasolid GmbH accessed on 02.11.2024 retrieved from: https://www.infrasolid.com/data/doc/White-paper/Whitepaper-The-Art-of-Fastest-Precision.pdf?c=20220609123356

[MH24b] Micro-Hybrid Electronic GmbH, "MH-Datasheet IR Strahler JSIR-350-4" accessed on 02.11.2024 retrieved from: https://www.microhybrid.com/de/shop/ir-strahler/ir-strahler-to39-mit-reflektor-und-filter-a1/

[Wie22] Wiegleb, G.: "Gasmesstechnik in Theorie und Praxis", 2. Auflage, Springer Vieweg, Wiesbaden, 2022

[Zac22] Zacher, S.: "Drei-Bode-Plots-Verfahren für Regelungstechnik", 2. Auflage, Springer Vieweg, Wiesbaden, 2022

Contact

Prof. Dr.-Ing. Falk Liebold
Cooperative University Thuringia
Electrical and Industrial electronic Engineering
falk.liebold@dhge.de