PAPER TITLE: **DESIGN AND DEVELOPMENT OF IIoT-BASED SYSTEM FOR BEHAVIOR PROFILING OF NONLINEAR DYNAMIC PRODUCTION SYSTEMS BASED ON ENERGY FLOW THEORY**

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SUBJECT: **APPENDIX 1 -** ***Current Profiler technical specifications and references***

Current Profiler is a hardware device for non-invasive, continuous monitoring, and acquisition of data on the intensity of electric current and profiling the behavior of the system/process/machine/device. The device schematic is provided in Fig. 1.

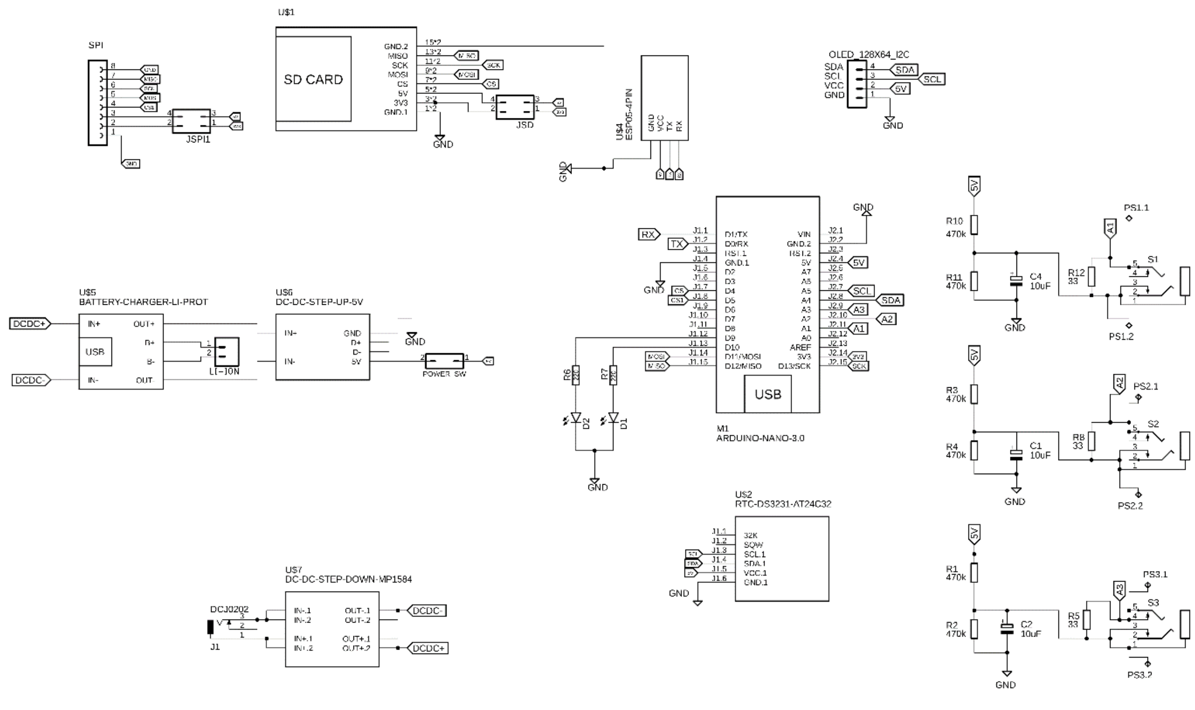
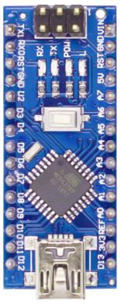


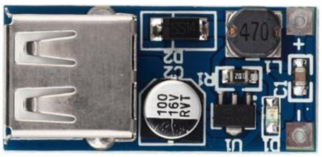
Fig. 1. Current Profiler structure schematic (perceptual layer)

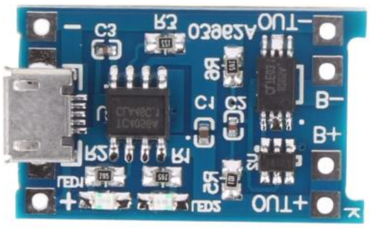
The main characteristics of integrated modules on the Current Profiler Printed Circuit Board (PCB) are provided in Table 1. These were not discussed in detail, due to a research scope, thus the detailed data sheets were referred to.

Table 1. Characteristics of integrated modules on Current Profiler PCB (Pt.1)

Microcontroller module (Arduino Nano V.3) [A1]				
Outlook	*Pin No.*	*Name*	*Type*	*Description*
	1-2, 5-16	D0-D13	I/O	Digital input/output port 0 to 13
	3, 28	RESET	Input	Reset (active low)
	4, 29	GND	PWR	Supply ground
	17	3V3	Output	+3.3V output (from FTDI)
	18	AREF	Input	ADC reference
	19-26	A0-A7	Input	Analog input channel 0 to 7
	27	+5V	Output or Input	+5V output (from on-board regulator) or +5V (from external power supply)
	30	VIN	PWR	Supply voltage

MP1584 Buck / Stepdown 3A Adjustable Regulator Module [A2]		
Outlook	*Name*	*Value*
	Input Voltage:	4.5V-28 VDC
	Output Voltage:	0.8V-18 VDC
	Continuous Output Current:	Max. 3 A
	Peek Output Current:	4 A
	Max. Efficiency:	92%
	Output Ripple:	<30 mV
	Switching Frequency:	100 kHz to 1.5 MHz
	Operating Temperature:	-40 to +85 ℃
	Dimensions (l*w*h):	22×17×4 mm

DC-DC USB Step-up Boost Power Supply Module 0.9V-5V to 5V [A3]		
Outlook	*Name*	*Value*
	Input Voltage:	0.9-5 VDC
	Output Voltage:	5 VDC
	Maximum Output Current:	600 mA
	Operating Temperature:	-40 to +85 ℃
	Max. Efficiency:	96%
	Dimensions (L×W×H):	34×16.2×7 mm

TP4056 1A Li-ion Lithium Battery Charging Module With Current Protection [A4]		
Outlook	*Name*	*Value*
	Charging accuracy:	1.5%
	Charging method:	Linear
	Full Charge Voltage:	4.2 V
	Input Voltage:	4.5-5.2 V
	Operating Temperature:	-10 to +85 ℃
	Rated Power:	4.2 W
	Over-Current Protection:	3 A
	Under-Voltage Protection:	2.5 V
	Dimensions (L×W×H):	30×17×6 mm

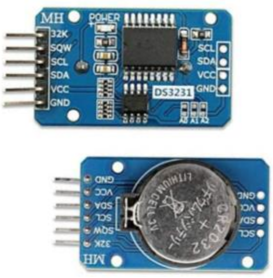
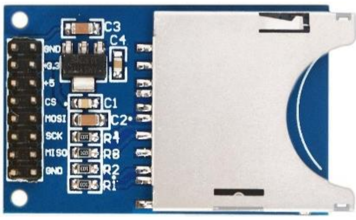
DS3231 I2C Precision Clock with AT24C32 Memory [A5]		
Outlook	*Name*	*Value*
	Operating voltage:	3.3 to 5.5 V
	Real-time clock chip:	DS3231
	Clock accuracy:	2 ppm
	Memory chip:	AT24C32 (32 Kb storage capacity)
	Operating Temperature:	-20 to +85 ℃
	On-chip temp. sensor accuracy:	±3 ℃
	I2C bus interface speed:	400 kHz max
	Time and Date Format:	Time: HH: MM: SS (12/24 hr) Date Format: YY-MM-DD-dd
	Dimensions (L×W×H):	38×22×14 mm

Table 1. Characteristics of integrated modules on Current Profiler PCB (Pt.2)

SD card reader module [A6]		
Outlook	*Name*	*Value*
	Supply voltage:	3.3 to 5.5 V
	Communication interface:	SPI
	Built-in voltage regulator:	3.3 V (LM1117)
	Installed card slot with ejector:	Yes
	Operating Temperature:	-20 to +85 ℃
	The diameter of mounting holes:	2.5 mm
	Chipset:	AMS1117
	Dimensions (L×W×H):	48×29.1×6 mm

I2C 0.96" OLED 128x64 Display [A7]		
Outlook	*Name*	*Value*
	Diagonal Screen Size:	0.96"
	Number of Pixels:	128 x 64
	Color Depth:	Monochrome
	Working Voltage:	3.3 to 5.5 V
	Power:	0.06W Max
	Viewing Angle:	>160 °
	Duty:	1/32
	Dimensions (L×W×H):	27.8 x27.3x 4.3mm
	Brightness (at 5V):	150 cd/m^2
	Interface:	I2C

The main characteristics of YHDC SCT-013-000 sensor are given in Table 2. This CT model has no internal burden resistor, thus a transient voltage suppressor limits the output voltage in the event of accidental disconnection from the burden. It is capable of developing sufficient voltage to fully drive a 5 V input. Moreover, the applied CT type is split core, enabling non-invasive implementation as being clipped straight onto the wires coming into the observed system.

Table 2. Characteristics of YHDC Split core current transformer SCT-013-000

YHDC Split core current transformer SCT-013-000 [A8]		
Outlook	*Name*	*Value*
	Input Current:	0~100A AC
	Output Mode:	0~50mA
	Non-linearity:	±3%
	Turn Ratio:	100A:0.05A
	Resistance Grade:	Grade B
	Work Temperature:	-25 ~ 70°C
	Dielectric Strength (between shell and output):	1000V AC/1min 5mA
	Dimensions (L×W×H):	56.8 x32.3x 21 mm
	Leading Wire in Length:	1m
	Cable Connector Type:	3.5 mm Stereo Jack (PJ307)

The main ESP8266 characteristics are listed in Table 3, while its ESP-07 Wi-Fi chip schematics are given in Fig. 2. The module core processor is ESP8266 which enables smaller sizes of the module, encapsulates Tensilica L106, integrates industry-leading ultra-low-power 32-bit micro MCU, with the 16-bit short mode, Clock speed support 80-160 MHz, supports the RTOS, integrated Wi-Fi MAC/BB/RF/PA/LNA, and onboard antenna. The module supports standard IEEE802.11 b/g/n agreement and a complete TCP/IP protocol stack [A9]. Therefore, it is suitable as a platform on which other modules can be added in order to be capable of networking, or, as is the case in this study, it can be integrated into other developing systems as a separate network controller.

Table 3. Characteristics of ESP8266 ESP-07 Wifi Serial Transceiver Module

ESP8266 ESP-07 Wi-Fi Serial Transceiver Wireless Board Module [A9]		
Outlook	**Name**	**Value**
	Interface logic voltage:	3.3 to 5.5 V
	Working voltage:	4.5 - 5.5V (On-board 3.3v LDO Regulator)
	Working current:	240 mA (MAX)
	Serial port baud rate:	115200 (default)
	Serial communication format:	8N1
	Antenna Type:	Ceramic (supports external antenna)
	Wireless Network Mode:	station / softAP / SoftAP + station
	Dimensions (L×W×H):	48×29.1×6 mm
	Wireless criteria:	802.11 b / g / n
	WIFI support at 2.4 GHz:	WPA / WPA2 security mode

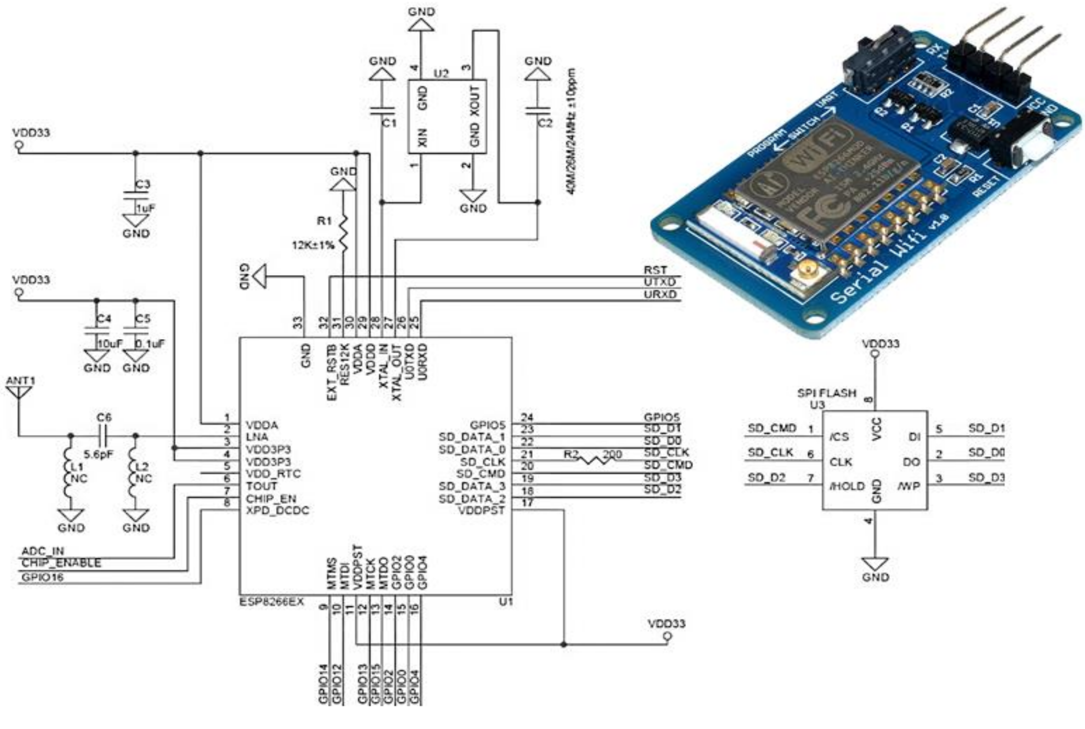


Fig. 2. ESP8266 Wifi Serial Transceiver Module Schematic and outlook (Network layer) [A9]

Based on the schematic provided in Fig. 1, and Fig. 2, it was possible to generate the PCB model which was afterward produced. This has illustratively been given in Fig. 3.

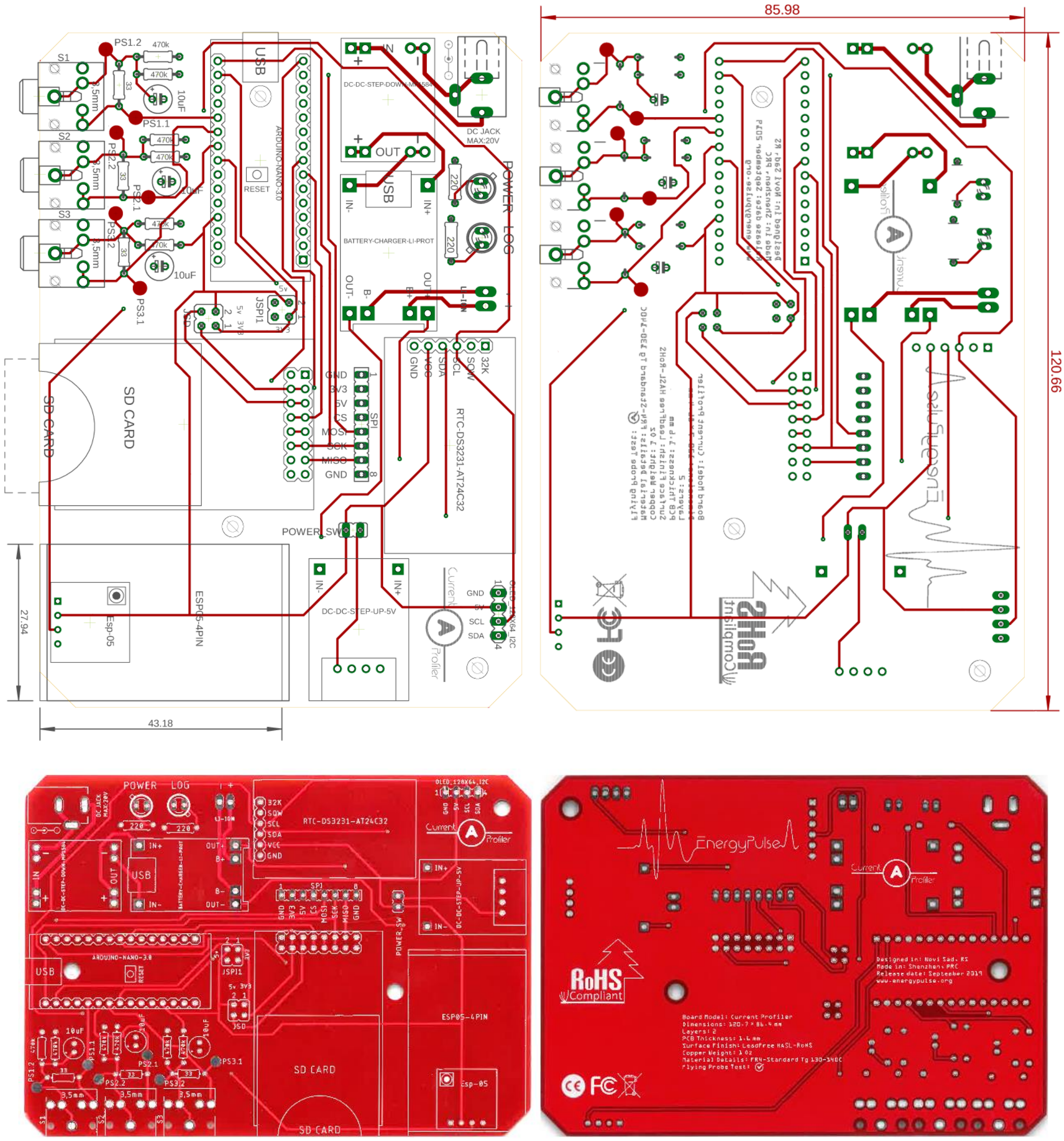


Fig. 3. Current Profiler PCB model (Up) and produced PCB (Down)

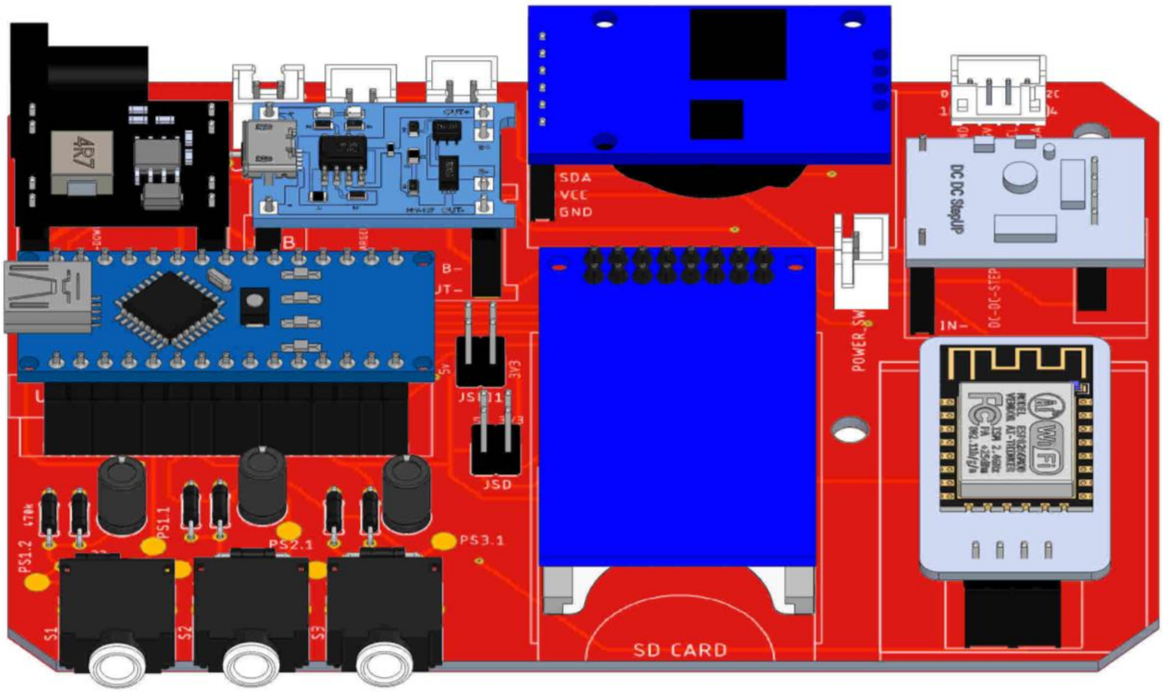


Fig. 4. 3D model of PCB with majority of accompanied components

The Current Profiler PCB, accompanied with previously mentioned electronic components is mounted in a customized, aluminum-made casing, as shown in the following figure (Fig. 5).

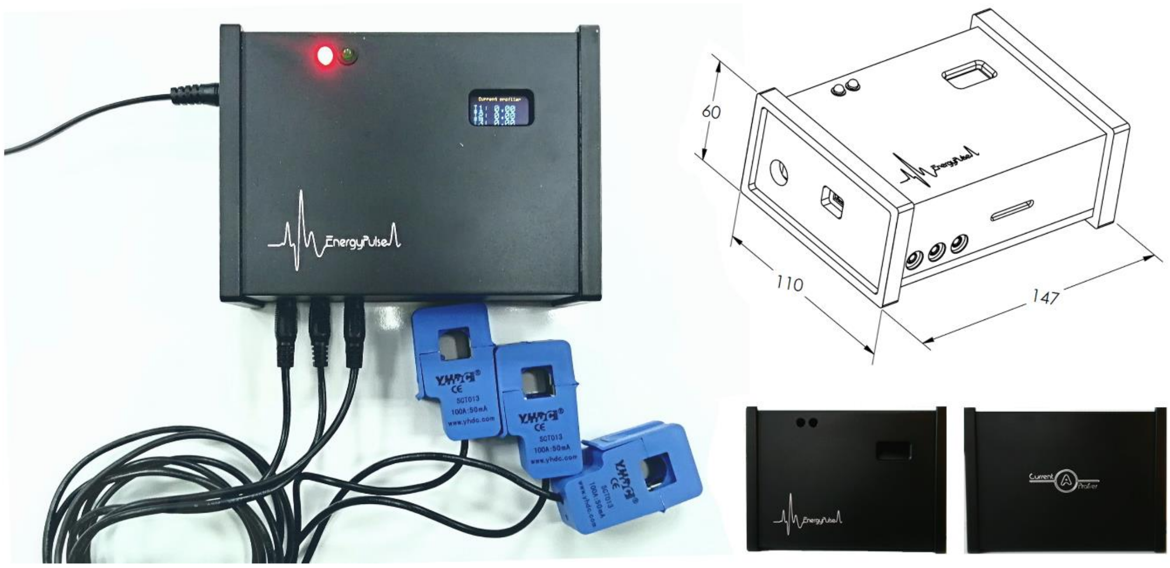


Fig. 5. Final outlook of Current Profiler with basic case dimensions

In order to provide clear insight regarding the overall system performance, a general technology concept of network infrastructure is given in Fig. 6.

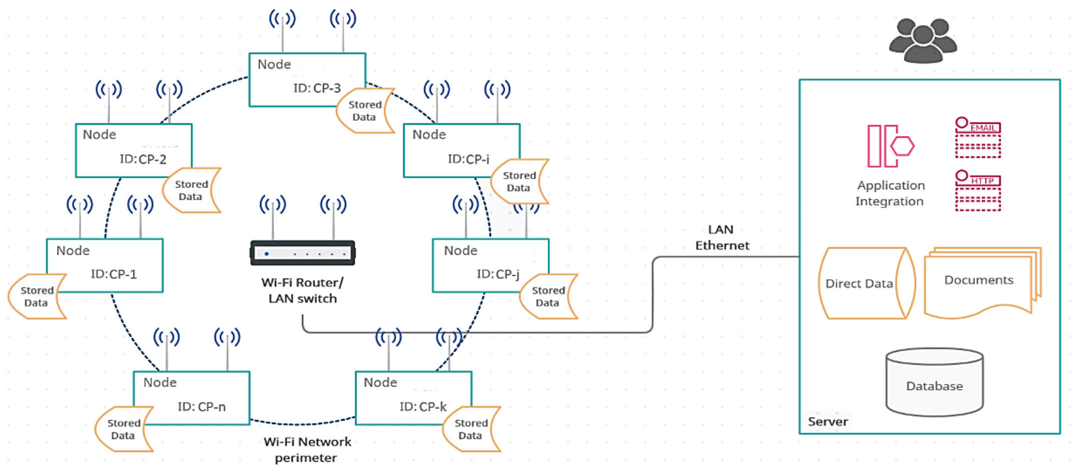


Fig. 6. The general technology concept of network infrastructure

The Current Profiler nodes (indicated as CP-1 to CP-n in Fig. 6) communicate via a hidden Wi-Fi network with a network Router/Switch which is connected to the client server via Ethernet. Client server hosts all necessary programs and codes to ensure data access via WEB App/Service. In addition, the communication was established using the MQTT protocol. MQTT is a publish/subscribe protocol, aimed at simple and lightweight messaging, designed for constrained devices, low-bandwidth, and unreliable networks. Here, easy communication between the server and many IoT nodes [A10-A14], makes it favorable to be implemented in the case of this research. The central server is a so-called broker which defines the topic, while sensor nodes then subscribe to it. The publishing was ensured by the Eclipse Mosquitto software that runs as a broker on the server. The software architecture of the developed solution is provided in Fig. 7.

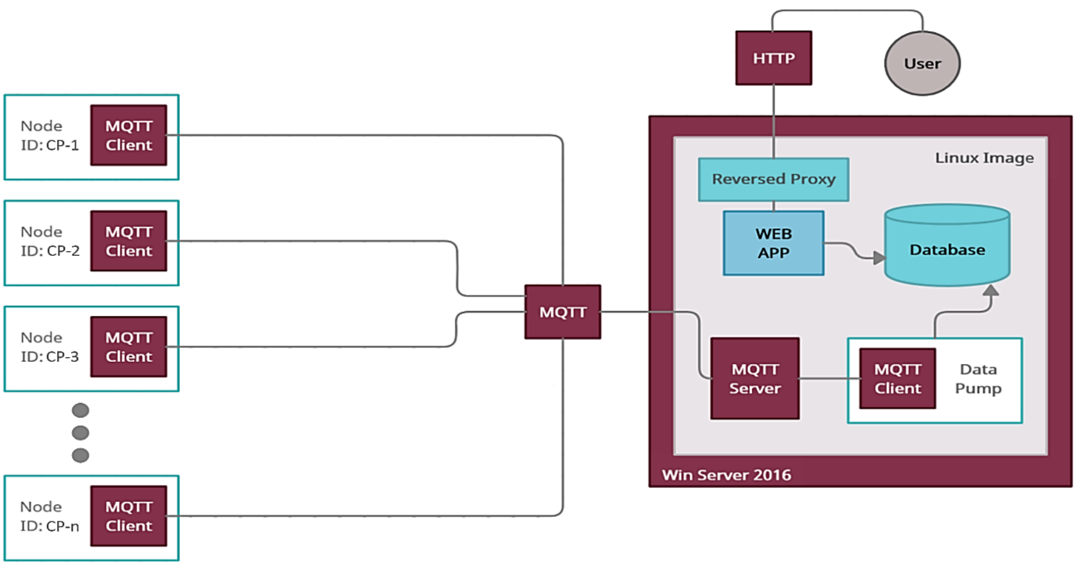


Fig. 7. The software architecture of the developed solution

Since the sensor data type is constructed as MQTT messages to be published to a self-hosted MQTT broker, a data pump service was necessary to be established for automated data import to the database. Therefore, all messages as time-series data could be stored in the InfluxDB database [A15]. The InfluxDB is a time-series database, optimized for fast queries regarding the stored sensor data in the time domain. Most importantly, the main reason behind the selection of InfluxDB is that it allows the use of Grafana [A16] for advanced data analysis, visualization, and representation (Fig. 8.).

Fig. 8. The Grafana-based GUI for Current Profiler data visualization

Grafana (Fig. 8.) is a responsive web-based data visualizing tool that provides easy setup of custom dashboards, alerts, and notifications from the data sets stored in the InfluxDB. In this specific case, Grafana was implemented on the server within the Linux image which was placed on a Windows-based server as an image via Docker. The Docker is an open platform for developing, shipping, and running applications, while the main reason for its implementation is the fact that it enables separation of applications from infrastructure in order to deliver software quickly, which significantly reduces the delay between writing code and running it in production [A17].

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