EuroCPS
Cyber-Physical Systems
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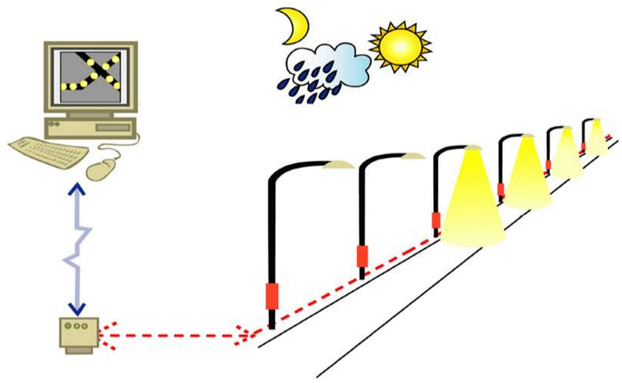
EuroCPS - SmartSSL

Project Results Summary

1. Purpose and scope of this document

This document is intended to summarize the outcome of the EuroCPS SmartSSL project and itemize the obtained results compared to the objectives outlined in the requirements.

2. Brief overview of the objectives

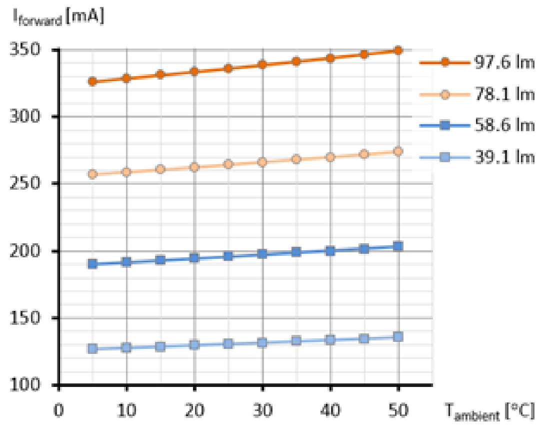


Street-lighting recently went through a drastic change offered by “LEDification”. The easy electronic controllability of LEDs as light sources triggered a new change of paradigm: integration of LED based luminaires into smart systems. Smart integration necessitates among others both adaptability to the environmental conditions and intelligent remote control that require communications systems based on a multi-layer data transfer protocol. In the framework of the SmartSSL project a “future-proof” solution has been developed, which is not restricted to lighting control but allows public lighting installations to play key roles in other smart city functions needed in outdoor public spaces such as communications with vehicles.

The result of the development is a new IoT system which can be installed in street-lighting luminaires and allows physical layer independent data transfer. The main functionality of the application layer of the protocol remains of course lighting control which is best implemented on the basis of existing standards (such as DALI), but the system allows the implementation of other communications tasks based on other application layer protocols. The key points of the specification and the requirements placed upon the system are the following:

Communication: Based on the objectives it is essential to provide a control unit for the luminaires including a communications interface with an architecture inspired by the principles of the OSI model, allowing high degree of independence of the physical medium available for data transmission and providing flexibility in the actual communications protocol being used; allowing street-lighting operators to tailor the smart LED luminaires to their existing infrastructure or re-configuring (updating) the luminaires when the infrastructure is upgraded.

Self-diagnostics and identification, intelligent LED driver capabilities: The system shall be capable of gathering as much data about the operation conditions of the LED luminaire and its environment as possible. The aim of collecting the housekeeping data is two-fold:



- The information gathered may be forwarded to the operator through the Internet. In this case, the state of a LED luminaire can be monitored remotely. Additionally, with the appropriate hardware, it can be possible to gather much more data than required to manage the operation of the LED luminaire itself. The additional information (e.g. temperature, humidity, wind, air pollution, traffic etc.) makes it possible for the LED luminaire to become a service provider for another smart city solutions
- The information gathered from the environment can be used to optimize the operation of the LED luminaire itself. Adjusting the LEDs' electrical operating point based on the actual environmental temperature may provide extra energy saving and increased safety and reliability of operation.

The system shall be a pilot implementation of self-identification in order to allow complete life cycle traceability of every individual module – this allows charging recycling costs of the product manufacturer. This is important to reduce the flood of cheap, low-quality products on the market where the recycling costs are not included in the price – providing an unfair market advantage to the manufacturers of such products.

3. Components of the developed system

3.1. Hardware components

There are two main hardware components developed in the framework of the SmartSSL project, namely the pylon unit and the lighting dispatcher. The pylon unit implements the intelligent LED driver functions including LED dimming, housekeeping data acquisition, and network communication, while the dispatcher unit serves as a data concentrator and a gateway for multiple pylon units in the same network. Figure 1 shows the demonstrational setup including the dispatcher unit and two pylon units integrated into HungaroLux's Pearllight 24G street lighting luminaires.

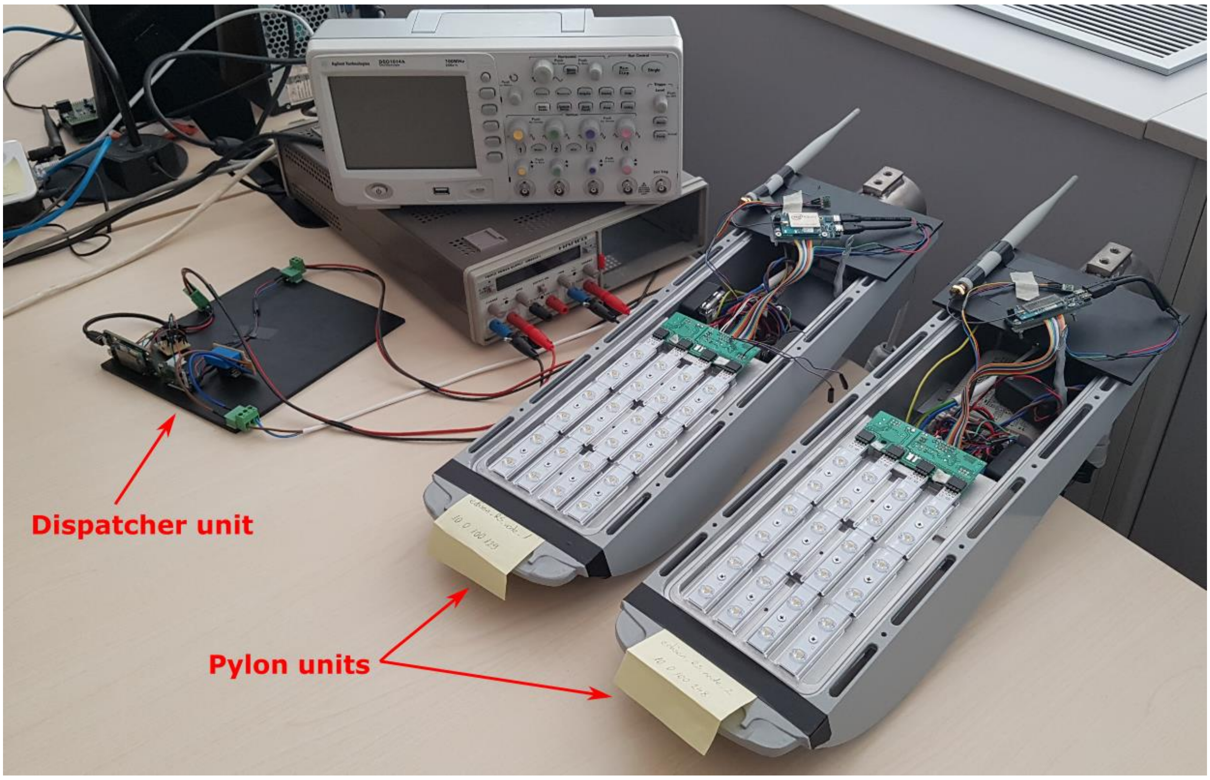


Fig. 1. The demonstrational hardware setup: the dispatcher unit and two pylon units.

Figure 2 shows the dispatcher unit including the Intel Edison compute module (see Section 4.1.1 in RD1) and the Yitran IT700 Power Line Communication (PLC) modem realizing the maintenance subnetwork interface (see Section 4.1.2 in RD1).

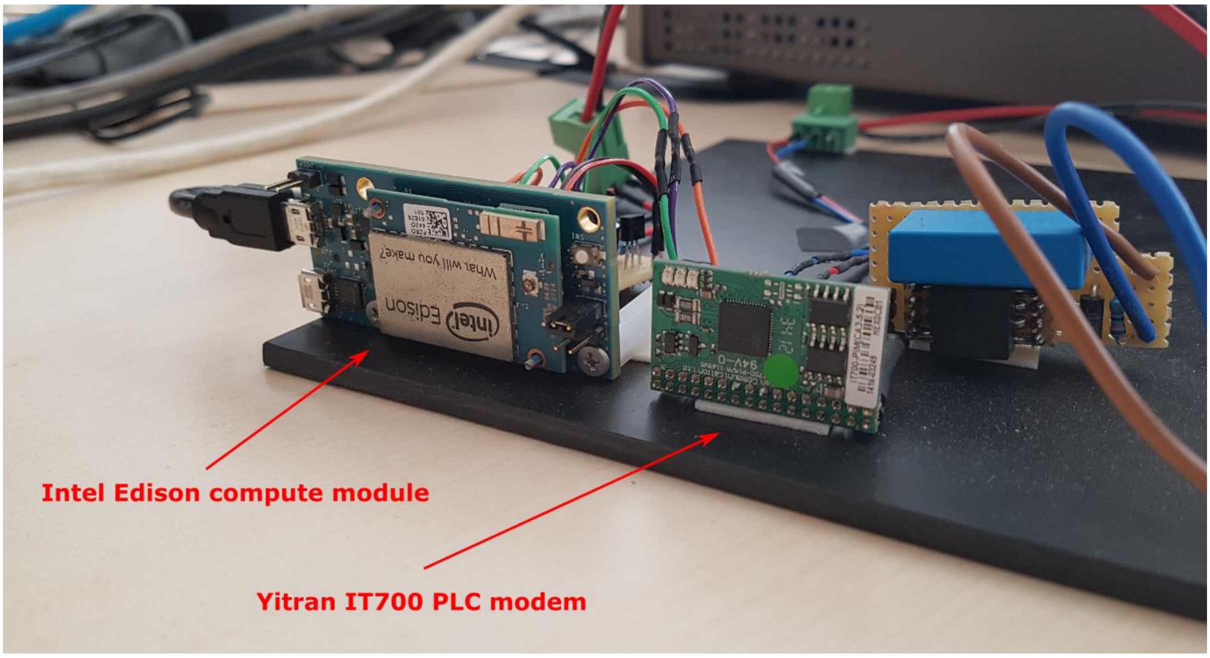


Fig. 2. The dispatcher unit.

Section 4.1 in RD1 discusses further details of the hardware components used in the demonstration prototype.

3.2. Software components

The delivered software components may be classified into two categories:

- **Low-level APIs and test**: Despite of the general, technology-independent nature of the whole concept behind the SmartSSL project, to demonstrate the operation of the system, a set of actual hardware modules and communication technologies have been selected. The low-level driver APIs to these hardware components have been developed to provide a baseline for the applications demonstrating the ideas of SmartSSL.
- **Demonstrational applications**: Multiple different software applications have been developed aiming to demonstrate how the SmartSSL system can fulfil its functional requirements:
    - Temperature-dependent light control: An application demonstrating how the developed system can optimize the power-consumption of an LED luminaire by measuring the ambient temperature and adjusting the forward current of the LED strings.
    - External user interface demo: An application intended to run on an external device, such as a cell phone and demonstrating the utilization of the external user interface of the pylon unit's external user interface.
    - Maintenance network demo: An application demonstrating how the SmartSSL system makes it possible for a lighting operator to access (monitor and adjust) the LED luminaires remotely through the Internet.

Section 4.2 in RD1 discusses the details of the software components developed to the demonstration system.

4. Requirements and solutions

In this section a list of the requirements placed upon the SmartSSL system is provided in conjunction with the explanation how the implemented system fulfils these requirements. This document is not intended to describe the technical details of the implementation, therefore, the appropriate references to the technical documentation's sections are provided.

4.1. Communication

***Requirement**. The system shall be flexible from the viewpoint of the physical layer communication interfaces. This may be achieved by considering the possible physical layer interfaces as byte-stream based solutions. Although the demonstrator itself will implement single physical layer interfaces, the data transfer protocols implemented will assume that the physical layer provides a simple byte-stream as data payload.*

Solution. As described in Section 3.1 in RD1, the developed LED driver module applies layered protocol structures over its physical layer communication interfaces. The software applications running on the demonstrational hardware include highly abstracted objects referring to the different communication channels and system resources. High level Application Programming Interfaces (APIs) are provided making it possible to modify the hardware under the application, without modifying the software itself. These APIs does not directly provide communication functions, but they express higher level services such as "get all housekeeping data from pylon #34" in case of the maintenance subnetwork interface's dispatcher side or "get humidity" in case of the sensor interface. The hardware providing housekeeping data and the physical layer of the communication links can be altered by fitting the low-level drivers and services of the new hardware/physical layer communication link to the pre-defined high level services applied in the current solution.

***Requirement**: There shall be an information exchange link between the lighting dispatcher and the intelligent LED luminaire control unit. Through this link the lighting dispatcher may*

- *control the dimming of the light according to the traditional, pre-defined schedule.*
- *acquire status data of the LED luminaires.*
- *acquire environmental measurement data provided by the LED luminaires.*

Solution: The above described data exchange link is referred to as "maintenance subnetwork" in Section 3.1 in RD1. Power Line Communication (PLC) is utilized in the demonstrational implementation to connect the LED luminaires to the lighting dispatcher. A simple data exchange service is provided by the API created to the PLC network making it possible to adjust the luminance of the LED strings and gather housekeeping data from the LED luminaire (see Section 4.2.3.2 in RD1). For the details of the PLC network hardware resources see Section 4.1.2 in RD1. For the details of the low level API created to the PLC network see Section 4.2.1.3 in RD1.

***Requirement**: It shall be made possible for the lighting dispatcher to connect to the Internet. This connection ensures the remote accessibility of the LED luminaire control units as well. The Internet connection makes it possible for the future applications to take advantage of the web-based and cloud services.*

Solution: As detailed in Section 3.2.1 in RD1, the dispatcher unit implements a communication interface to the Internet. This connection is utilized by the demonstrational application detailed in Section 4.2.3.3 in RD1. In this realization, the Internet-connection is based on WiFi. The graphical user interface of the web-application accessing the LED luminaires through the internet is shown in Figure 3. This application directly accesses the dispatcher unit, the central node of the PLC network to which the pylon units are connected too. The user interface of the dispatcher unit can be used to send queries to the pylon units through the PLC network (commands setting their luminance and initiating housekeeping data transmissions) and to receive their replies. The received replies are then decoded and visualized by the dispatcher unit.

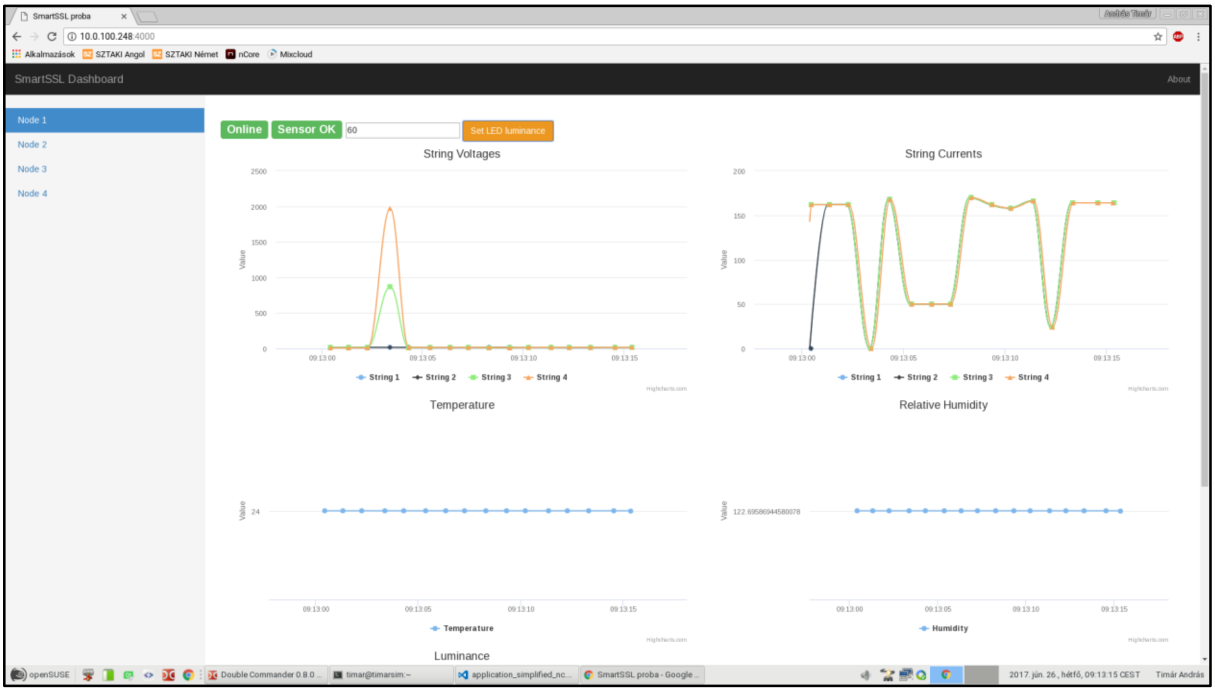


Fig. 3. User interface on the PC

***Requirement**: There shall be a data link between the intelligent LED luminaire driver and the so-called external devices which may want to access the same information as the lighting dispatcher or a subset of that information. In the future applications this link is going to be a highly flexible ad-hoc link with more rigorous security requirements. In this demonstration project no user roles and security levels shall be defined. The external devices may access the same information about the LED luminaire driver as the lighting dispatcher itself, via a flexible, unique, physical layer-independent data transfer protocol.*

Solution: As detailed in Section 3.2.2 in RD1, the LED luminaires (the pylon units) implement a communication interface to external devices. This connection is utilized by the demonstrational application detailed in Section 4.2.3.4 in RD1. In this realization, the external devices can access the same data set as the dispatcher unit through an ad-hoc WiFi connection. The external device (e.g. a cell phone) may connect to the LED luminaire and it can modify the LED luminance and acquire all housekeeping data of the LED luminaire. Figure 4 shows the graphical user interface of the web-application running on the external device (a cell phone in the demonstrational setup).

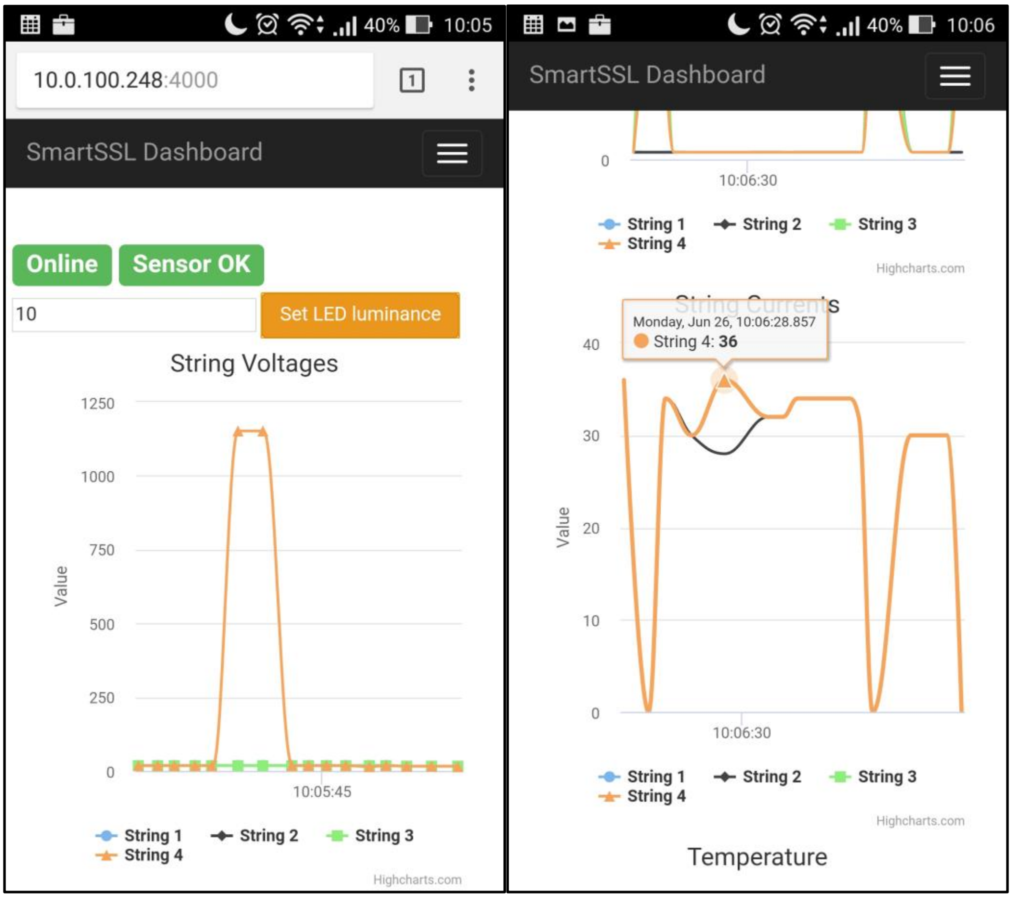


Fig. 4. User interface on a smartphone

4.2. Self-diagnostics and intelligent LED driver capabilities

***Requirement**: The need for sophisticated operating point control of LEDs, which takes into consideration the environmental variables and the actual multi-domain characteristics of the LEDs places considerable demands upon the LED driver circuitry.*

- *A set of environment variables shall be measured. In this demonstration project the ambient temperature and the relative humidity are the variables measured to implement intelligent operating point adjustment.*
- *Open-loop or closed-loop control system for the LED strings based on the acquired environmental data.*

Solution: As detailed in Section 3.2.2 in RD1, the LED luminaire includes a LED DAQ and control unit and a sensor unit. These two ancillary units make it possible for the intelligent LED driver module to gather environmental information such as ambient temperature and humidity, moreover, they make it possible to adjust and optimize the electrical operating point of the LED luminaire according to the environmental conditions. The temperature-dependent light control application has been quantitatively tested by placing one of the pylon units into a thermal humidity test chamber (see Section 4.2.3.1 and 4.2.4.2 in RD1). Figure 5 shows the measurement setup.

Fig 5. Thermal humidity test chamber measurement setup.

The isoflux (5 lm) characteristics of the luminaire obtained by the aforementioned test setup is shown in Figure 6. The aim of the experiment was to see whether the control system is capable of keeping the radiant/luminous flux on the value characteristic to the luminaire on room temperature, while the ambient temperature changes on a wide range (from -30 °C to +60 °C).

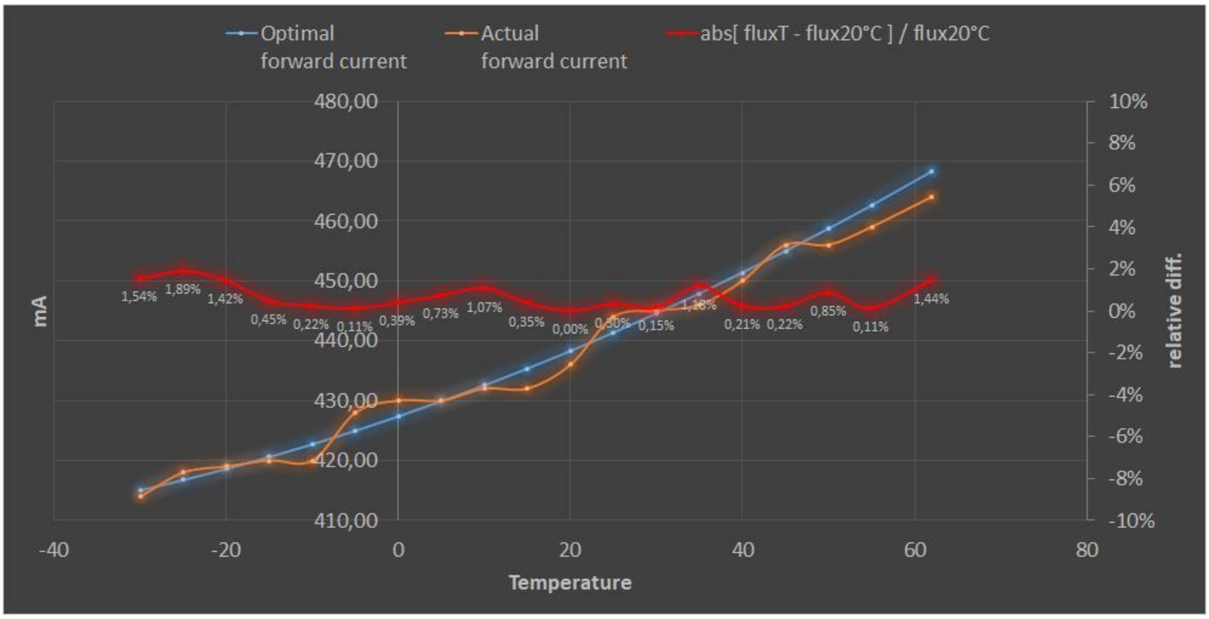


Fig 6. Isoflux (5 lm) characteristics of the luminaire.

It may be seen in Figure 6 that the radiant flux provided by the luminaire has been kept on a constant value by adjusting the forward current applied on the LED strings. The relative error of the radiant flux on different temperatures (the difference between the actual radiant flux and the reference radiant flux at room temperature divided by the reference radiant flux) is kept in a range of 1-2%.

4.3. Self-identification

***Requirement**: The system shall make it possible to assign an individual ID to every LED luminaire to make complete life-cycle traceability possible.*

Solution: As detailed in Section 4.2.3.2 in RD1, the intelligent LED driver module has its own identifier defined in the application layer data exchange protocol. In this demonstrational implementation, these identifiers are defined by the software running on the LED driver module, which means that the can be modified by a simple firmware update, however, in future applications these identifiers can be fixed hardware IDs as well. Moreover, the housekeeping data set provided by a single LED driver module can also be extended with further hardware IDs identifying the submodules of the installation.

5. Referred documents

RD1	EuroCPS SmartSSL - Final Technical Documentation