# Indoor Positioning Systems Based on Visible Light Communication: State of the Art

## Introduction

For outdoor scenarios, GPS is used extensively. However the positioning accuracy is several meters which is unaccaptably large for indoor scenarios. Outdoor positioning tech thus cannot be used indoors.

Two features make light available for positioning:

1. The light strength varies according to differenet light sources, which can be readily detected by light sensors embedded
2. The light strength is stable at different times of a day, avoiding site-survey and database maintenance.

* Received Light Strenght of the light source can be used for localization

VLC-based IPS advantages:

* Can be used in RF sensitive areas like hospitals…
* LED offers a narrow beamwidth: more precise AOA information
* VLC has little influence from multipath interference (primary energy comes from line of sight link)
* Can be installed inexpensively since they utilize existing lightingsystems.
* Higher precision than traditional positioning

## Indoor Positioning technologies and VLC

### Various indoor positioning technologies

Different techniques: frequency modulation, cellular networks, zigbee, Wi-Fi, Infrared, Ultrasound, Bluetooth, RFID and UWB?

### VLC

RF-bandwidths are failing to meet requirements

* VLC is promising alternative

High speed response characteristics of White-LED devices , at the same time of lighting, LEDs can send information. VLC has the following advantages:

* Cost efficiency: VLC uses existed lighting infrastructure to communicate
* Broad Bandwidth: between 385 and 800 THz
* Energy efficiency: LED’s are energy efficient and use it’s energy to communicate at the same time
* Communication Security: Visible light can not penetrate most objects and walls, and links can be kept confedential

## VLC-based-IPSs

### VLC-based Indoor Positioning techniques

* The device-free-IPS analyses how a human body changes the pattern of received signal strength to detect and locate human in an indoor environment.
* VLC-based-IPSs with high precision (up to a few centimeters)
* VLC-based positioning systems: Eplison, Luxapose, LIPS, PIXEL

1. LED Technology:
   * White-LEDs (Blue led with phosphor or RGB combination)

Blue led is commonly used for easy implementation and lower cost. Second method can use Colour Shift Keying (CSK) to modulate the data: better performance in comms

* + RGB-LED (slightly higher modulation bandwidth data rates and lower response time than white leds  
    can transmit data by modulating RED, GREEN and BLUE separately.

1. Modulation Method: the modulation method for VLC should achieve not only the data rate but also to meet the demand of illumination: dimming control and flicker control
   * On-Off Keying (OOK): just turning the LED on and off, no dimming or flicker control
   * Pulse Position Modulation (PPM): the position of the transmitted pulse identifies the transmitted symbol. This method is Simpler but with lower spectral efficiency and a lower data rate. (therefor lots of different PPM’s are proposed)
   * Orthogonal Frequency Division Multiplexing (OFDM)
   * Color Shift Keying (CSK)
   * Carrier-less Amplitude and Phase (CAP)
2. Types of Receivers: two classes (Photodiode (PD) and image sensors)
   * Photodiode: easy, high data rate, most likely to choose the method of RSS, TOA and TDOA algorithms.
   * Image Sensors: less expensive, camera based

### Taxonomy of the VLC-based IPSs

Decisions on 3 key features: mathematical method, sensor-assisted method, and positioning optimization method.

### Mathematical Method

1. Proximity (simplest positioning method) based on the range of a known station or a near AP

Advantages: low power, high security, extensive area

1. Triangulation (using geometric properties of triangles)
   1. AOA angle of arrival: localization using angles
   2. TOA using propagation delay
   3. RSS: received signal strength: alternative approach to estimate the distance between the mobile device and the base station using the attenuation property of emitted signal strength
2. Fingerprint: the feature or c characteristics of signals that are location dependen. In most times, TSS is considered as a type of fingerprint. It is assumed that in different areas the features of signals are different. 2 types of fingerprint:
   1. Map-based fingerprint: 2 stages
      1. Offline stage
      2. Online stage/runtime stage
   2. Map-free fingerprint

### Sensor-Assisted Method

4 types of conventional sensors: image positioning/ image sensor, accelerator, light sensor and multiple optical receivers.

1. Image Sensor: capturing images and then detect the presence of the luminaires in the image, decoding their transmitted identifiers and/or locations.
2. Accelerometer: received power can be used to derive the distance between the receiver and LED’s (received pwer can be affected by the distance, the irradiance, and incidence angles.
3. Light Sensor: a light sensor has a deterministic sensitivity to both distance and incident angle of the light signal => therefore suitable for using as the receiver of VLC-based positioning
4. Multiple Optical Receivers: requires multiple transmitters or receivers.

### Optimization Method

For achieving better accuracy and improving the trackability:

1. Filtering Technique: 2 classes
   1. KF: requires that the system is dynamic and the measurement model is linear. EKF can linearize the nonlinear model.
   2. PF:
2. Spring Model: A Localization Algorithm based on a Spring Model (LASM): computational complexity may be reduced with the same accuracy
3. Normalizing Method: ICI can be mitigated by the Carrier Allocation (CA) method

## Discussions, challenges, countermeasures and Lessons Learned

### Discussions:

See table 7

### Challenges:

* ICI (Inter-Cell Interference) is main theme throughout VLC-based positioning
* Multipath reflections: may decrease accuracy like corner area’s
* Lack of fingerprint and effect of the orientation of receiver: lack of correct identification of LEDs, similar RLS may be captured at different positions
* Long Delay: no real-time service
* LED to Internet connectivity: to create a VLC-based broadband access network
* Other challenges such as ambient light noise, synchronization, flickering, receiver design and energy efficiency, uplink and RF augmentation, mobility and coverage

### Countermeasures:

* ICI mitigation: right use of cells
* Mitigating the effect of multipath reflections: right calibration approach for corners and edges
* Solution to lack of fingerprint and effect of the orientation of the receiver
* Decreasing delay: a multiple access scheme based on block encoding TDM can shorten the delay time efficiency
* LED to internet connectivity: need to design a novel technology providing high speed internet connectivity and reducing the cost

### Lessons Learned:

* The multiple transmitters and a single receiver in IPS : multipath reflection interference such as ICI technology needs to be solved
* Choosing the suitable LED technology and modulation method can improve the system performance. RGB-LED: higher data rate than white LED at the cost of complexity
* Using some sensors reasonably can obtain good positioning precision. i.e. using the accelerometer to obtain the orientation of the receiver can improve the estimated accuracy of the distance, the light sensor has a deterministicsensitivity to both distance and Incident angle. Thus it can infer the distance and angular information from the light signal
* Designing suitable calibration methods and using correct optimization method can reduce the positioning error.