Indoor Localization Using Visible Light Communication And Image Processing

Aswin P K
Department of ECE
NIT Calicut
Kerala, India-673601
achuakaaswin@gmail.com

Shyama P
Department of ECE
NIT Calicut
Kerala, India-673601
shyamap95@gmail.com

Lyla B.Das, member IEEE
Department of ECE
NIT Calicut
Kerala, India-673601
lbd@nitc.ac.in

***Abstract*—Indoor localization using short-range wireless communication techniques has gained popularity over the Global Positioning System due to the latters limited capability to provide indoor positioning information. This paper reports the implementation of a multi-transmitter visible light communication based indoor localization system that offers a moderate data rate and indoor positioning with sub-meter accuracy. The work includes a prototype of the proposed system with four transmitters and a receiver module mounted on a stationary base. The transmitted data was Manchester encoded, and Binary Amplitude Shift Keying modulated. Multiple access of channel was achieved using Time Division Multiple Access technique. The receiver module used a PIN photodiode to detect the light signal and indoor positioning or localization was implemented using received signal strength technique.**

Keywords*—indoor localization, Received Signal Strength, visible light communication, Time Division Multiple Access, Manchester encoding, Binary Amplitude Shift Keying.

I. INTRODUCTION

The development of indoor robotic systems, and smart, multipurpose, hand-held devices such as mobile phones and tablets, has necessitated an accurate, easy to implement, and cost effective indoor localization system. Indoor localization refers to locating the position of an entity (stationary or mobile) within a building. It is essential for systems such as automatic floor cleaners, security robots, store navigation, guided museum tours, and indoor building space mapping. Unlike outdoor localization, where Global Positioning System (GPS) plays an effective role, indoor localization using GPS is inaccurate due to poor GPS signal strength. Thus, systems based on wireless sensor networks are deployed [4]. But such systems require the installation of additional hardware and can be expensive. An alternative would be to implement an indoor positioning system using the lighting system within the building, by exploiting the possibilities of Visible Light Communication (VLC). This would eliminate the cost for additional hardware and would also be easy to implement.

This work proposes a system capable of implementing localization based on VLC as shown in Figure 1. A VLC transmitter to send Binary Amplitude Shift Keying (ASK) modulated data and a receiver module to decode the same were designed and implemented. Time Division Multiple Access (TDMA) was used to achieve multiple access of the channel. Localization was achieved using a multi-transmitter arrangement by employing a Received Signal Strength (RSS) based algorithm and sub-meter accuracy was attained. Image processing techniques were used to improve this result.

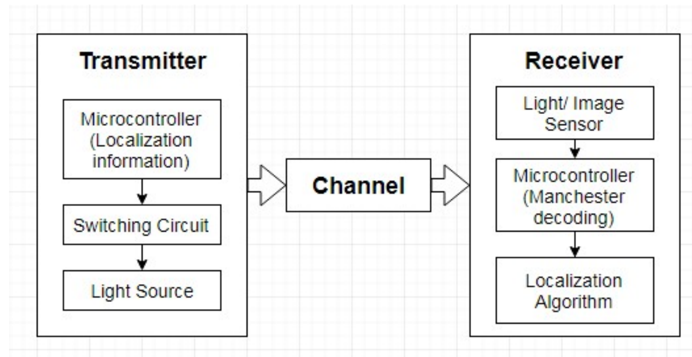

Fig. 1: Proposed VLC System Block Diagram

II. VLC TRANSMITTER

A. VLC Transmitter Design

A microcontroller, light source, and switching circuit constituted the VLC transmitter. The static data to be transmitted was stored in the flash memory of the microcontroller and was Manchester encoded and Binary ASK modulated before transferring to the light source via a switching circuit. TDMA channel access scheme was employed to accommodate multiple transmitters.

Light Emitting Diode (LED) was chosen as the transmitter light source due to better switching frequency, longer lifetime and better power efficiency when compared to other sources such as incandescent and fluorescent lamps. The transmitter uses two 10 W LEDs in parallel to increase the transmitter - receiver separation. A transmitter- receiver separation of 1.6 m was achieved with this arrangement.

A DC switching circuit was used, as AC switching circuit introduced 50 Hz power supply noise into the light stream that caused severe noise at the receiver. As the two 10 W LEDs in parallel drew high current, a power transistor of high rating (I_c=1.5 A) was used. The transmitter design is shown in Figure 2. A metal sheet of approximate dimension 5x6 cm was used as a heat sink for the LEDs, to prevent heating and consequent damaging of the system. A transmission rate of 100 kbps was achieved using this arrangement. But considering the bandwidth limitations of the receiver, the transmission bandwidth was chosen to be 20 Kbps.

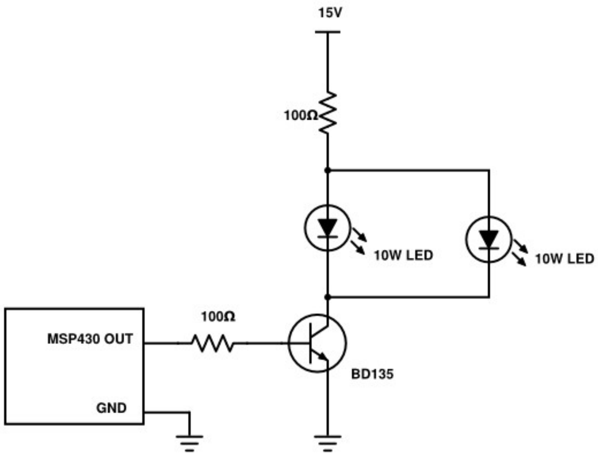

Fig. 2: VLC Transmitter Design

B. Data Encoding

Data was transmitted by Manchester encoding the bit stream using an MSP430G2553 microcontroller. For the purpose of testing, a ml-sequence of length 15 was repeatedly sent, preceded by 2 start bits and followed by a stop bit. A delay of fifty '0'bits was introduced between successive transmissions. The sequence after encoding is shown in Figure 3. Manchester encoding was chosen to avoid long sequences of 0 bits from interfering with the lighting application of the system. Each transmitter continuously transmitted an 8-bit code that was used to uniquely identify the transmitter during localization.

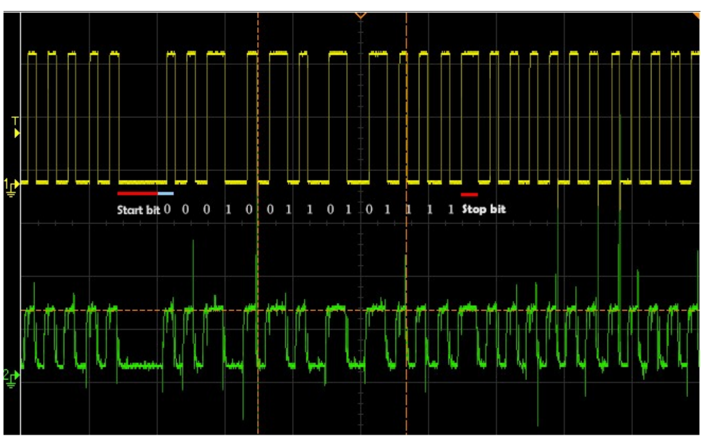

Fig. 3: Manchester Encoded Transmitted signal

Each message symbol consisted a START bit, followed by the 8-bit unique code (Manchester encoded) and a STOP bit. The START bit was a LOW signal of 2 time period duration and the STOP bit was a HIGH signal of 4 time period duration.

Start bit (2T)	Message (8 bit)	Stop bit (4T)

Fig. 4: Message Symbol structure

The START bit was used to synchronize the receiver, while the STOP bit conveyed the end of a transmission. Since the symbol space was small (4 symbols), the use of an error control code was avoided. Each time period (T) was 52 s and an entire symbol duration was 728 s (start - message - stop).

C. Multiple Transmitter Arrangement

Multiple transmitters were used to achieve localization. The multi-transmitter arrangement was formed using four transmitters, placed on the corners of a square of side 87 cm. Each transmitter sent a unique code. All the transmitters were synchronized for TDMA using interrupts. The entire time slot was divided into slots of 40 message symbols each. Each 40 symbol slot, was further divided into four slots of 10 symbols, where transmitter 1 transmits in slot 1, transmitter 2 in slot 2, transmitter 3 in slot 3, and transmitter 4 in slot 4.

III. VLC Receiver

The receiver module comprised of an optical sensor circuit for sensing and conditioning the light signal and a microcontroller to decode the data and run the localization algorithm.

A. VLC Receiver Design

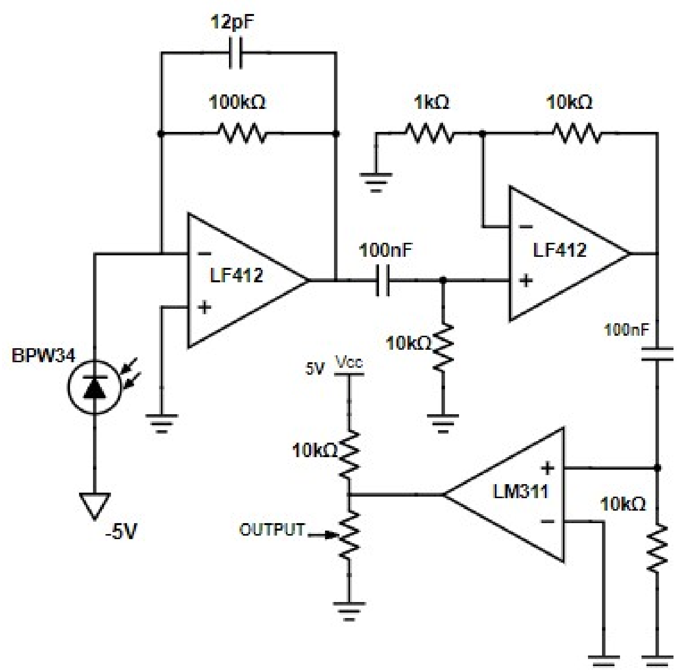

Fig. 5: VLC Receiver Design

The receiver design is shown in Figure 5. A PIN photodiode was used, followed by a transimpedence amplifier to convert the current signal from the photodiode to voltage signal. The output of the transimpedence amplifier was passed through a high pass filter of cut-off frequency 159 Hz to remove DC as well as 50Hz power supply noise. The signal was further amplified for localization purposes. This was followed by another HPF stage to remove any remaining DC signal. Finally, the signal was passed through a comparator and a voltage divider to ensure that it stayed within 0-3.3 V range for the MSP430 microcontroller to operate upon.

Figure 6 shows a comparison of transmitted and received signals and Figure 7 shows received signal in the presence of 4 transmitters.

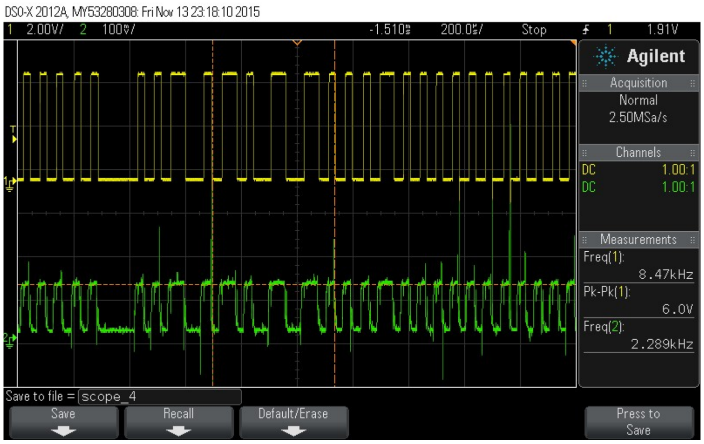

Fig. 6: VLC Receiver Design

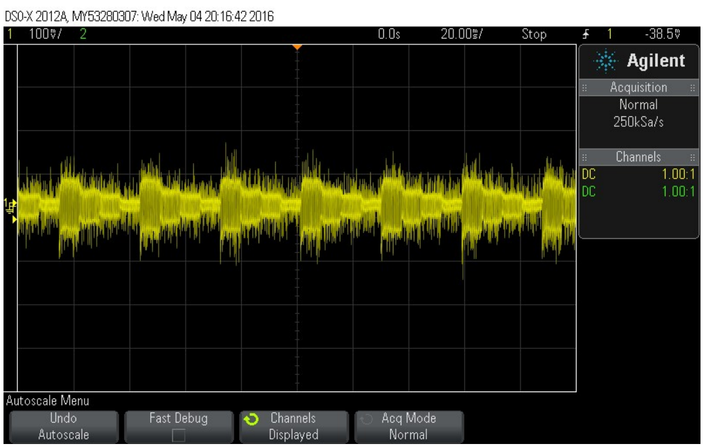

Fig. 7: VLC Receiver Design

B. Manchester Decoding

Fig 7 shows the Manchester decoding algorithm. The output from the receiver circuit was fed into the microcontroller, and decoded by sampling the signal twice per bit duration. Synchronization of the sampling sequence was achieved using the START bit. The received signal strength was calculated by passing the output before the comparator stage to the ADC pin of MSP430. The ADC value was read out during the STOP bit to ensure maximum strength.

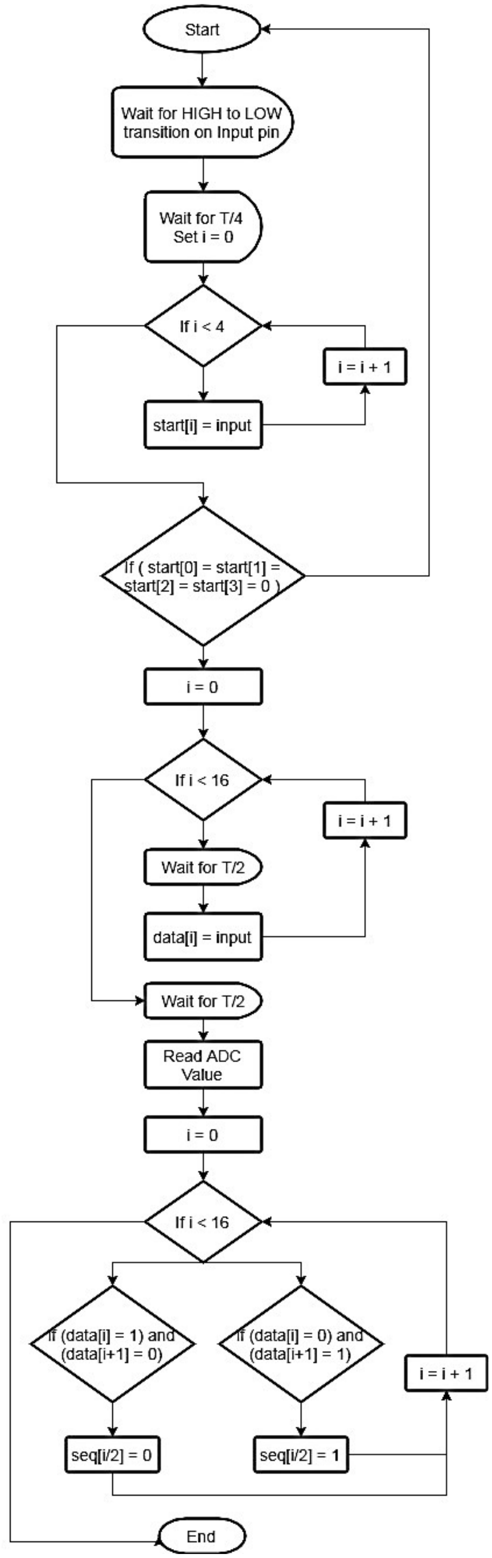

Fig. 8: Manchester Decoding Algorithm

IV. LOCALIZATION

A. Localization based on RSS

The signal strength of each transmitter was obtained from the receiver module. The approximate position of the stationary base that holds the receiver was obtained by comparing these values with a previously captured and consolidated set of values. This value may be combined with the distances obtained from image processing, to calculate the location of the stationary base with a greater precision.

B. Overview of arrangement

The area beneath the four-transmitter arrangement was divided into a 4x4 matrix labeled as shown in Figure 9. Each matrix cell measured approximately 22x22 cm.

The receiver was placed in each of these cells and the position was calculated using an RSS based algorithm and cross-verified. Better efficiency could be achieved by conducting more training sessions.

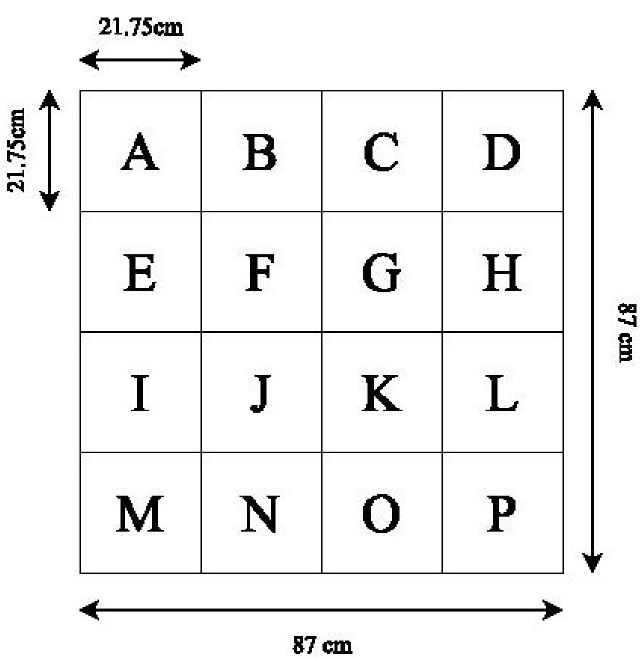

Fig. 9: Matrix arrangement for localization

C. Localization Algorithm

Training Session:

1) Place the receiver in cell A
2) Take signal strength readings for all 4 transmitters and record
3) Move to next cell
4) Repeat steps 2,3 until all cells are covered
5) Repeat steps 1-4, N times
   The value of N decides the accuracy of the system. For the implemented system N was chosen as 5. Each cell reading was obtained by averaging over 80 received symbols strength.

Position calculation:

1) Place the receiver in a random position.
2) Take signal strength readings for all 4 transmitters - t1, t2, t3, t4.
3) Calculate the probability of occurrence of the values t1 - t4, in each cell (A-P).

$$p(\textit{cell is X}) = \sum_{i=1}^{4} \frac{ki}{max(X) - min(X)}$$

where max(X) and min(X) are the maximum and minimum recorded values in cell X and k1−k4 are weights assigned. ki=0 if ti is not in the range min(X) to max(X), for the particular set of values at cell X.

4) Find cell with maximum probability of occurrence. Assume it to be the location.

D. Image processing based localization

Images were continuously captured using a camera mounted on the floor. These images were converted from RGB scale to HSV scale using OpenCV and the light sources were isolated by filtering out the unnecessary values using suitable HSV ranges. The edges of the sources were detected using suitable filters (Canny filter) and the pixel coordinates of the center of each of the contours were obtained by applying an averaging function. The pixel coordinates of the center of the image were then calculated. These coordinates indicated the position of the camera i.e., stationary base with respect to the light sources. Using these, the pixel distance of the receiver module from each of the LED source was calculated. Actual coordinates of the receiver module were calculated after transforming the pixel coordinate system into a mesh coordinate system. A linearization factor, alpha, was multiplied with the pixel distances to convert them to actual distances. Alpha was experimentally determined and depends on the vertical distance between the receiver module and the transmitter plane. Figure 10 and 11 depicts a sample result obtained from the arrangement.

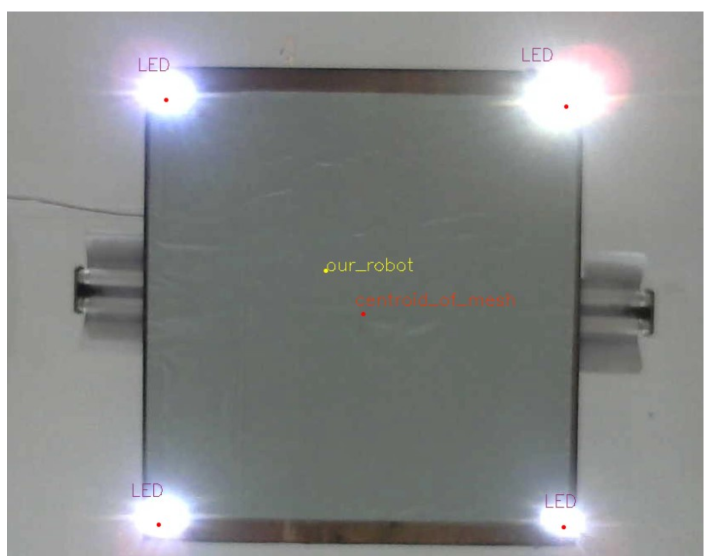

Fig. 10: Sample image of the transmitters (after processing for localization)

Figure 10 shows the final processed image where the location of the four transmitters and stationary base were identified. The transmitters are marked in red and labelled as LED and the position of the stationary base is marked in yellow and labelled as ourrobot in the image. The centroid of the transmitter mesh was also calculated and this is labeled as centroidofmesh in the image. These coordinate values were used for position estimation.

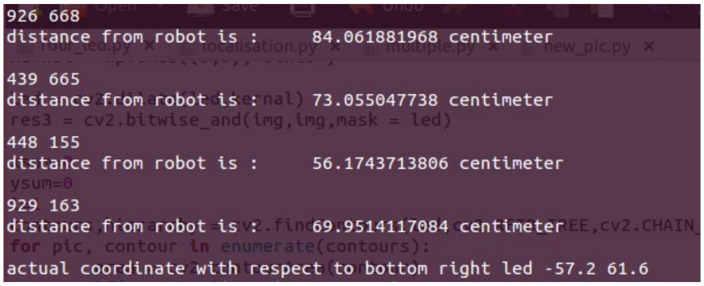

Fig. 11: Sample result from image processing

Figure 11 shows the results calculated after identifying the necessary pixel coordinates from Figure 10. The image displays the coordinates of each of the transmitter followed by the distance (in cm) of the stationary base from the respective transmitter. The actual coordinates of the stationary base (in cm) with respect to the bottom right LED in Figure 10 was also calculated.

V. Conclusion

The proposed indoor positioning system was implemented with sub-meter accuracy under experimental limitations. A VLC based simplex communication system was established with 20 kbps data rate and transmitter-receiver separation of 1.6 m. 10 W LEDs were used as transmitter light source and a PIN photo diode formed the core of the receiver. Though transmission rate of over 100 kHz was achieved using the designed VLC transmitter, the receiver bandwidth limitation introduced by the photo-detector reduced the effective communication rate to 20 kbps. A TDMA based channel multiple access was implemented for the purpose of indoor localization, with four transmitters. The transmitters were arranged on the corners of a square and the received signal strength from each of the transmitters was analyzed to implement localization with sub-meter accuracy. An RSS based algorithm was used for indoor positioning. Image processing based localization was done to improve the accuracy of the system. But image processing was not integrated into the prototype system as the camera demanded a larger transmitter-receiver separation for proper transmitter detection than that was achievable with the current system.

The proposed system provides better accuracy compared to the existing indoor localization systems which utilizes technologies like WiFi, ZigBee and Bluetooth [21]. It is easy to incorporate in smart devices and has lower implementation cost compared to other existing indoor localization systems that provide sub-meter accuracy using Unidirectional Ultra Wide Band (UWB) and Ultra High Frequency (UHF) technologies [4].

The data rate of the prototype was limited by the photo-detector at the receiver. With better photo-detectors, higher data rates can be achieved. Transmitter-receiver and inter-transmitter separations can be improved by increasing transmitter power, thereby aiding the incorporation of image processing-based techniques. Error control coding can be included to improve quality of the data transmission thus making the proposed VLC and image processing-based indoor localization technique an efficient and reliable alternative to the existing systems.

Acknowledgment

We express our sincere gratitude to Prof. Lyla B Das, Associate Professor, and Mr. K. R. Anandan, Senior Mechanic, Department of Electronics and Communication Engineering, National Institute of Technology Calicut for their support and expert guidance.

References

[1] OBrien, Dominic C., et al., *"Visible light communications: Challenges and possibilities"*, IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications, 2008.

[2] Verma, Shalini, Astha Shandilya, and Ashutosh Singh, *"A model for reducing the effect of ambient light source in VLC system"*, International Advance Computing Conference (IACC), 2014.

[3] Daimiwal, Nivedita, M. Sundhararajan, and Revati Shriram, *"Comparative analysis of LDR and OPT 101 detectors in reflectance type PPG sensor"*, International Conference on Communications and Signal Processing (ICCSP), 2014.

[4] Liu, Hui, et al., *"Survey of wireless indoor positioning techniques and systems"*, Systems, Man and Cybernetics, Part C: Applications and Reviews, pp 1067-1080, 2007.

[5] U blox Super sense datasheet Available at: https://www2.u-blox.com/images/downloads/ProductDocs/NEO−4SData Sheet(GPS.G4-MS4-06107.pdf

[6] Hightower, Jeffrey, Roy Want, and Gaetano Borriello, *"SpotON: An indoor 3D location sensing technology based on RF signal strength"*, Department of Computer Science and Engineering, University of Washington, UW CSE 000202, 2000.

[7] Ni, Lionel M., et al., *"LANDMARC: indoor location sensing using active RFID"*, Wireless networks vol-10,issue-6, pp 701-710, November 2004.

[8] Klapproth, Alexander, and Stefan Knauth, *"Indoor Localisation Technologies and Applications"*, Proceedings of the embedded world 2007 Conference, 2007.

[9] Kotanen, Antti, et al., *"Experiments on local positioning with Bluetooth"*, Information Technology: Coding and Computing [Computers and Communications], 2003.

[10] Sathiya.T, Prof. E.Divya and Prof. S.Raja, *"Visible Light Communication for Wireless Data Transmission"*, International Journal of innovative research in electrical, electronics, instrumentation and control engineering Vol. 2, Issue 2, February 2014.

[11] OBrien, Dominic, et al., *"Indoor visible light communications: challenges and prospects"*, Optical Engineering + Applications, International Society for Optics and Photonics, 2008.

[12] Yang, Zhice, et al., *"Wearables can afford: Light-weight indoor positioning with visible light"*, 13th Annual International Conference on Mobile Systems, Applications and Services (ACM), 2015.

[13] Kuo, YeSheng, et al., *"Luxapose: Indoor positioning with mobile phones and visible light"*, Proceedings of the 20th annual international conference on Mobile computing and networking, (ACM), 2014.

[14] Li, Liqun, et al., *"Epsilon: A visible light based positioning system"*, 11th USENIX Symposium on Networked Systems Design and Implementation (NSDI), 2014.

[15] Jovicic, Aleksandar, Junyi Li, and Tom Richardson, *"Visible light communication: opportunities, challenges and the path to market"*, Communications Magazine, vol-51, pp 26-32, 2003.

[16] Zhang, Weizhi, MI Sakib Chowdhury, and Mohsen Kavehrad, *"Asynchronous indoor positioning system based on visible light communications"*, Optical Engineering, vol-53, 2014.

[17] Yasir, Muhammad, Siu-Wai Ho, and Badri N. Vellambi, *"Indoor localization using visible light and accelerometer"*, Global Communications Conference (GLOBECOM), 2013.

[18] Wang, Thomas Q., et al., *"Position accuracy of time-of-arrival based ranging using visible light with application in indoor localization systems"*, Journal of Light Wave Technology, vol-31, no-20, pp 3302-3308 October 15, 2013.

[19] Varatharajan, R., et al., *"Visual analysis of geospatial habitat suitability model based on inverse distance weighting with paired comparison analysis"*, Multimedia Tools and Applications, pp 1-21, June 2017.

[20] Yasir, Muhammad, Siu-Wai Ho, and Badri N. Vellambi, *"Indoor positioning system using visible light and accelerometer"*, Journal of Lightwave Technology, vol-32, no-19, pp 3306-3316, June 2014.

[21] Haute, Tom, et al., *"Performance analysis of multiple Indoor Positioning Systems in a Health Care Environment"*, International Journal of Health Geographics, 15.1, February 2016.