# INFRARED ACTIVE BEACON APPLICATION EVALUATION FOR MOBILE ROBOT LOCALIZATION IN AGRICULTURE

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**Abstract.** Mobile robots can replace humans in variety of different tasks. Although mobile robots can perform tasks safer, quicker, more efficient, more precise etc. than human, the accurate localization system is a must for successful mobile robot operation in the working environment. According to literature mobile robots can help a lot in the agriculture industry where time consuming, tiring, routine and expensive tasks (labor salaries) are very common. Our previous research has shown that infrared technology is appropriate for mobile robot localization for specific agricultural tasks. In this paper we analyze overall infrared technology applications for mobile robot localization and we offer a novel localization system based on 1) stationary infrared active beacons and 2) rotary infrared light detection and collimation system installed on moving robot. The localization system prototype has been built during the research. The key factors determining mobile robot localization accuracy and maximum localization distance experimental evaluation has been done. The maximum localization distance for our experimental setup is approximately 20 m while active beacon detection angular accuracy is 2.89º, thus mobile robot localization error is not exceeding 7 cm and localization time is about 7 seconds.

**Keywords:** infrared active beacon, mobile robot, robot localization, agriculture.

## 1. Introduction

Microcontrollers and embedded processors have reached computing power that ensures a complex algorithm execution in a real-time that facilitates a wide application of stationary and mobile robots that is increasing over the last several years [1]. Modern technologies offer mechatronic products, including mobile robots, which can beat human workforce in sense of speed, quality, efficiency, price etc. The agriculture is one of the candidates for mobile robot invasion for overall improvements in the agricultural industry [2-4]; however mobile robots must be equipped with accurate localization system to perform the agricultural tasks [2; 5-8]. Our previous research has shown that infrared technology is appropriate for mobile robot localization for specific agricultural tasks: 1) seeding, 2) sensing (no plant or info), 3) patrol (weed control, disease seeking, soil sampling), 4) transportation outside working area, 5) transportation inside working area, 6) sensing (plant patrol), 7) follow-up operations and 8) harvesting with some conditions like size of total area (inside and outside working areas), absence of natural landmarks in the ambient environment (furrows, plant lines etc.), necessity for high localization accuracy.

This paper is organized as follows. In Section 2, we summarize the most common mobile robot localization applications based on infrared technology. In Section 3, we introduce our novel mobile robot localization system and evaluation steps. In Section 4, we show the results of our system evaluation experiments.

## 2. Infrared light applications in localization tasks

Infrared technology based mobile robot localization applications can be divided in two groups: 1) localization based on active beacons and 2) localization based on passive landmarks [9]. The difference between these groups is that in the first case the infrared emitter(s) are placed on the stationary beacon, so the infrared signal is emitted from beacon itself while in the second case the beacon or landmark is reflective, so it is passive and it does not emit the infrared signal itself. In both approaches the beacons are located in the environment at previously defined coordinates and mobile robots are scanning the environment to detect the beacons and to calculate robots' location by triangulation or trilateration algorithms [10]. There is another approach where no beacons are used at all. The robots are equipped with both infrared emitters and infrared sensors to detect each other to ensure multi-robot relative localization [11].

One of the infrared beacon applications [12] is implemented as coded circles on the ground or floor where mobile robot is moving on. The infrared sensor is located on the mobile robot while infrared emitting diodes are mounted on the ceilings and they are emitting unique code; however they cannot emit simultaneously because of interference effect and thus limits application in multi-robot systems. Localization accuracy depends on circle count and their overlapping. Researchers suggest combining this technique with odometry measurements to improve accuracy; however odometry can strongly suffer from uneven terrain in outdoor environments and it is uneconomic to build special structures to simulate ceilings outdoors.

In other research the infrared sensor disc approach is described [13] where 16 sensors are placed on circular disc at equal angles over 360º. The localization distance for such system is approximately 10m and localization accuracy depends on infrared active beacon count and reflection issue. The validity coefficient of sensor readings is trigonometrically calculated that indicates direction to the detected beacon. The angular sensitivity of infrared sensor depends on the distance between sensor and emitting diode, thereby the closer is sensor, the bigger is angle of view and bigger the angular beacon detection error accordingly.

In the year 1992 the mobile robot localization technology based on infrared light was patented [14]. The active beacons are detected by infrared sensor which is placed behind a narrow aperture, that reduces the angle of view and improves the angular beacon detection accuracy; however the patented system is stationary mounted on the mobile robot, so the mobile robot must spin over the vertical axis to scan the ambient environments for beacons and it can introduce the odometry error. Although the narrow aperture improves the angular accuracy, there is still relatively big angle of view, which can be further reduced by collimator [15]. Convex lens can be used as collimator; however parallel beams can be obtained only in theory, because manufacturers cannot produce ideal lenses [15]. The alternative for convex lens is a thick aperture or parallel plates that form a tunnel for infrared beams. Such collimators are used to localize unmanned aerial vehicles indoors [16]. The authors are using two 4x4 cm infrared absorbing plates with a distance of 2 mm between plates for each collimator. The research reports few centimeters localization error in the distance of 2 m between UAVs and localization system. The UAVs are equipped with infrared emitting diode while collimators are motorized by stepper motors to ensure 360º rotation.

There are several applications where passive landmarks are used for mobile robot localization. Hagisonic StarGazer [17] offers mobile robot localization system where infrared emitting diodes are oriented vertically up together with photo camera, which is sensitive to infrared light. The unique non-symmetric reflective landmarks are mounted on the ceilings at known positions and angles ensuring 2.5-5 m circular localization area according to manufacturer's technical specification. Although manufacturer promises the repeatable 2 cm localization accuracy and 1º bearing resolution, independent research has shown worse results [18]. The researchers point out three main problems: 1) the localization error reach 170 cm, 2) switching between landmarks introduces shift and discontinuity problem in mobile robot position curve and 3) in 5-10 % of all cases there are unidentified or misidentified landmarks. Researchers offer to use extended Kalman filter to fuse Hagisonic StarGazer data with odometry data to improve the mobile robot localization accuracy indoors.

We analyzed the infrared technology applications where some are mentioned above, and we developed a novel mobile robot localization system combining advantages of analyzed infrared technology applications.

## 3. A novel mobile robot localization system and evaluation procedures

Our mobile robot localization system consists of 1) stationary infrared active beacons located at known positions and 2) rotary infrared light detection and collimation system. The beacons are equipped with Vishay TSUS5202 infrared light emitting diodes and programmed to emit unique infrared light pattern modulated over carrier frequency of 38 kHz to fit the sensor sensitivity. The Vishay TSSP4038 infrared sensor is mounted on the circular rotary platform, which is motorized via friction-gear transmission by a stepper motor with 0.027º angular resolution. In the front of the sensor, parallel to sensor, there are two circular sector type plates with adjustable aperture size between the plates. The radius of the plates is 10 cm. The sensor itself is hidden in shielding box, which reflects infrared light outside the box, see Fig. 1. A. The interior of the shielding box and collimating plates are covered with infrared light absorbing layer of rubber soot. The practical application is focused on triangulation technology, see Fig. 1 B.

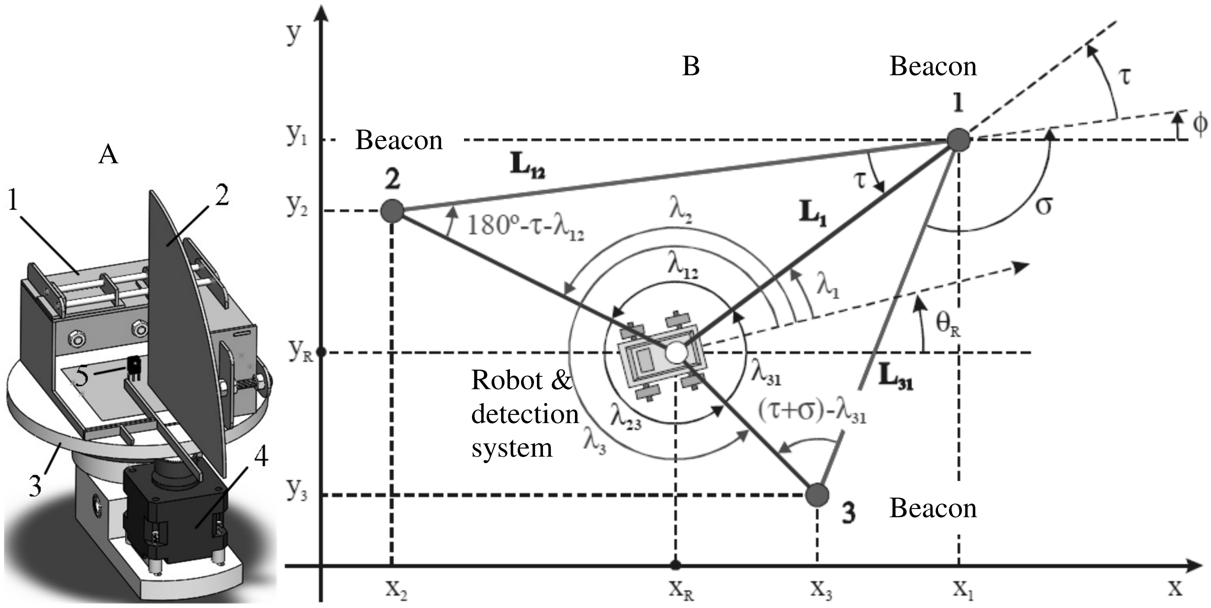


Fig. 1. **Mobile robot localization by triangulation algorithm and rotary infrared light detection and collimation system:** 1A – shielding box, 2A – collimating plates with adjustable aperture (one plate not shown), 3A – rotary platform, 4A – stepper motor, 5A – infrared sensor, 1B – beacon 1, 2B – beacon 2, 3B – beacon 3, $L_{12}$ – distance between beacon 1 and beacon 2, $L_{31}$ – distance between beacon 3 and beacon 1, $L_1$ – distance between robot and beacon 1 (Fig. 1 B [19])

The optical parts of such system can be affected by 1) sun, 2) DC light, 3) LCD backlight etc. [20]. The localization distance depends on 1) emitting diode forward current, 2) emitting diode forward current and radiant intensity relation, 3) fitness of wavelength and carrier frequency between diode and sensor, 4) ambient temperature, 5) emitting diode working mode (overheating possibility), 6) emitting diode radiant intensity angular displacement, 7) minimum sensor irradiance, 8) sensor sensitivity angular displacement, 9) sensor power supply voltage, 10) invers square law signal attenuation, 11) reflection (tunnel effect prolongs the localization distance), 12) the aperture size (reduce irradiance on sensor), 13) system montage accuracy [21-22]. The active beacon detection angular accuracy depends on 1) size of collimating plates, 2) aperture size, 3) distance between emitting diode and sensor, 4) reflection (increases rotation angle and/or affect signal detection symmetry), 5) stepper motor resolution and gearing, 6) system montage accuracy.

There are several techniques how to evaluate infrared emitter parameters. Firstly, the total radiant power can be easily measured with high repeatability with simple mechanical setup, which is independent of optical irregularities in the infrared emitting diode lens and variations in mechanical positioning of the infrared emitting diode; however radiant power does not describe the angular displacement of infrared radiation thus provides incomplete information for optical engineers [23].

Secondary, it is possible to measure radiant intensity that is much more informative and can be used for optical system modelling and calculations; however it is hard to get reproducible measurements because optical and mechanical axis of the infrared emitting diode almost never coincide due to manufacturing production tolerances [23-24].

Finally, irradiance is informative as well, but it depends on system setup geometry. Larger cone angles increase reproducibility of irradiance measurements, but reduce its accuracy, because radiant power density is not homogeneous over a large diameter [23]. When distance between infrared emitting diode and sensor is at least 10 times bigger than dimensions of diode itself, the inverse square law is applicable to calculate irradiance at specific distance [24]. These aspects should be taken into account for reliable evaluation of optical system.

To evaluate our mobile robot localization system we calculate theoretical irradiance at specific distance and infrared emitting diode forward current according to the datasheet [21]. Radiant intensity is provided at distance of 1 m, so it is equal to irradiance at this distance [25]. According to inverse square law, it is possible to calculate irradiance at different distances (1).

$$E_e = \frac{I_e}{d^2}, \quad (1)$$

where $E_e$ – irradiance, mW·m$^{-2}$;
$I_e$ – radiant intensity, mW·sr$^{-1}$;
$d$ – distance, m.

The infrared sensor outputs two-state digital signal. It remains high when no infrared signal is detected and drops low when signal is present. We modulate 20 carrier cycles of 38 kHz infrared signal for emitting diode with repeat time of 50 carrier cycles. According to data provided by manufacturer, the sensor output pulse with corresponds to irradiance on sensor surface depending on distance between diode and sensor or diode forward current. This experiment is important to obtain the right distance for further measurements, because radiant flux is not homogenous as we mentioned before. Afterwards we can proceed with aperture adjustment and collimator rotation experiments to evaluate mobile robot localization system characteristics. Finally, we perform localization based on triangulation algorithm to evaluate the accuracy of our system.

## 4. Results and discussion

The sensor output pulse width experiment (1000 measurements for every point) shows good visual correlation between manufacturer data at distance of 0.5 m (irradiance interval 0.1-10 mW·m$^{-2}$) and 0.05 m (irradiance interval >10 mW·m$^{-2}$), see Fig. 2.

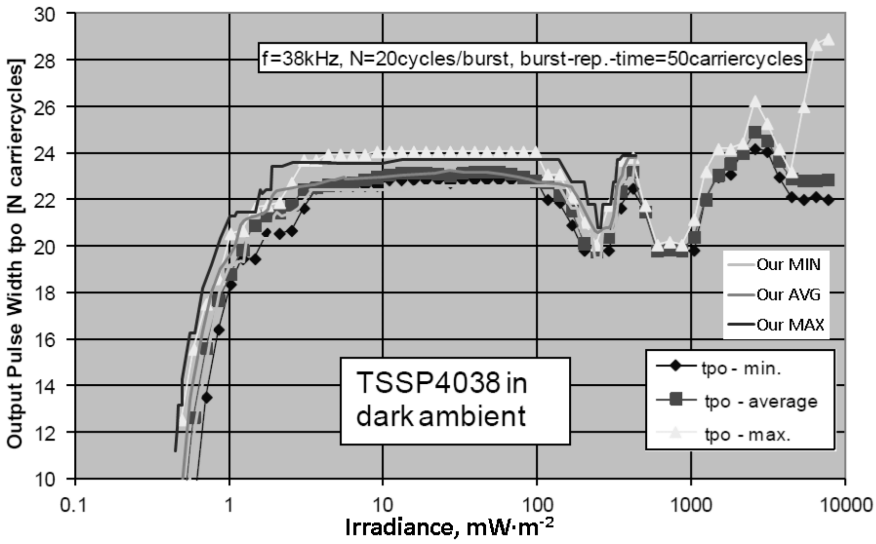


Fig. 2. **Sensor output pulse width result comparison to manufacturer data**

The other experiments are performed in the irradiance range 0.1-1 mW·m$^{-2}$, where it is possible to point the corresponding sensor output pulse width value for each irradiance value. The irradiance detected by infrared sensor is not decreasing after collimator aperture size is reduced smaller than infrared sensor lens diameter, see Fig. 3. A. It means that sensor sensitivity zone is smaller than sensor lens dimensions, thus minimum aperture size can be smaller than sensor lens diameter increasing the active beacon detection angular accuracy, see Fig. 3.B.

The infrared signal detection distance tests using Vishay TSAL6200 high power infrared emitting diode at 200 mA forward current demonstrates the maximum distance of approximately 20 m and active beacon detection angular accuracy of 2.89º for that distance.

Finally, the mobile robot field localization experiments are carried out. The mobile robot localization error is not exceeding 7 cm and localization time is about 7 seconds in 10x10 m square area using three active beacons, see Fig. 4. The figure shows localization points – the coordinates determined by robot and validation points where the robot is actually situated. Also angle $\theta$ between robots central axis in moving direction and $X$ axis of coordinate system is validated for each point. The results show, that angle localization error do not exceed 0.95º or 0.3 % of full angle. Localization accuracy is affected by friction gear slippage and inconsistent gear diameters. Optical encoder disc can be used to eliminate these localization accuracy error sources.

It is should be noted that the proposed localization system can be practically used also in multi-robot systems.

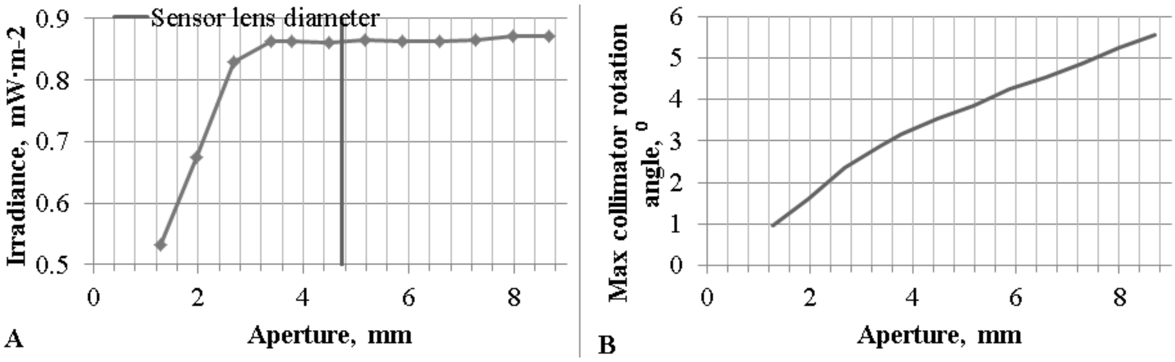


Fig. 3. **Collimator aperture impact on irradiance and maximum rotation angle**

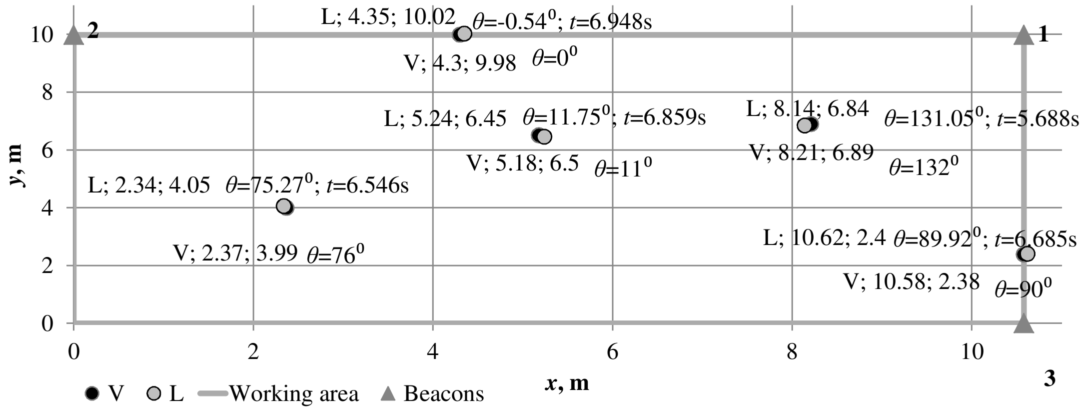


Fig. 4. **Mobile robot localization field experiment:** V – validation, L – localization, $\theta$ – robot orientation, $t$ – localization time

## Conclusion

A novel mobile robot localization system using active infrared beacons is developed and validated at distances not exceeding 20 m. For the given distances the system performs with 7 cm spatial and 1º angular localization error. The localization process takes approximately 7 s.

Comparing to different localization technologies the localization distance is not the worst, moreover infrared active beacons are relatively cheap, and thus multiple beacons can be installed at mobile robot working area. The infrared active beacon approach is arguably the most appropriate for agricultural tasks where repeating determined landmarks are not present, like furrows and plant lines where image analysis and/or proximity sensors could be easely applied. Possible use cases are operation in orchards, lawn mowing, short-range transportation etc.

The rotary infrared light detection and collimation system installed on the mobile robot can be significantly improved to reduce the mobile robot localization error and localization time ensuring real-time localization while robot is moving. Such improvements can be 1) optical encoder disc, 2) timing belt gearing or direct drive, 3) multiple collimating apertures and corresponding infrared sensors on separate channels.

## References

1. Industrial Robot Statistics [online] [21.04.2014]. Available at: http://www.ifr.org/industrial-robots/statistics/

2. Eaton R., Where Robotics and Agriculture Meet: Autonomous Vehicles for Precision Farming. [online] [01.04.2014]. Available at: http://www.sensorsandsystems.com/article/features/7319-where-robotics-and-agriculture-meet-autonomous-vehicles-for-precision-farming.html
3. Freitas G., Zhang J, Hamner B., Bergerman M., Kantor G. A Low-Cost, Practical Localization System for Agricultural Vehicles. Intelligent Robotics and Applications Lecture Notes in Computer Science, vol. 7508, 2012, pp. 365-375.
4. Foglia M.M., Reina G. Agricultural Robot for Radicchio Harvesting. Journal of Field Robotics, vol. 23(6/7), 2006, pp. 363–377.
5. Biber P., Weiss U., Dorna M., Albert A. Navigation System of the Autonomous Agricultural Robot “BoniRob”. Workshop on Agricultural Robotics: Enabling Safe, Efficient, Affordable robots for Food Production, Portugal, 2012, pp. 1-7.
6. Li M., Imou K., Tani S., Yokoyama S. Localization of Agricultural Vehicle Using Landmarks Based on Omni-directional Vision. 2009 International Conference on Computer Engineering and Applications, vol. 2, pp. 129-133.
7. Mehta S.S., Burks T.F., Dixon W.E. Vision-based localization of a wheeled mobile robot for greenhouse applications: A daisy_chaining approach. Computers and electronics in agriculture, vol. 63, 2008, pp. 28-37.
8. Blackmore B.S., Choudhury S. Fuzzy Landmark Detection in Simultaneous Localisation and Mapping for Agricultural Robots [online] [02.04.2014]. Available at: http://www.frc.ri.cmu.edu/~sanjibac/Research/safar/Fuzzy%20Landmark%20Detection%20in%20Simultaneous%20Localisation%20and%20Mapping%20for%20Agricultural%20Robots.pdf
9. Kurian J. A Beacon based localization system for autonomous mobile robots and its applications in traffic and transport control. Doctoral thesis, 2008. 179 p.
10. Chivarov N., Shivarov S. Ultrasonic Positioning System for Mobile Robots. Problems of Engineering Cybernetics and Robotics, vol. 62, 2010, pp. 43-52.
11. Kemppainen A., Haverinen J., Roning J. An Infrared Location System for Relative Pose Estimation of Robots, Proc. 16-th CISM-IFToMM Syposium of Robot Design, Dynamics, and Control (ROMANSY 2006), Warsaw, Poland, 2006, pp. 379-386.
12. Bae J., Lee S., Song J. Use of coded infrared light for mobile robot localization. Journal of Mechanical Science and Technology, vol. 22, 2008, pp. 1279-1286.
13. Krejsa J., Vechet S. Infrared Beacons based Localization of Mobile Robot. Electronics and electrical engineering, automation, robotics, 2012, pp. 17-22.
14. Mattaboni P.J. United States Patent. 1992. Patent Number: 5165064.
15. Balsam J., Ossandon M., Bruckb H.A., Rasooly A. Modeling and design of micromachined optical Seoller collimators for lensless CCD-based fluorometry. The Royal Society of Chemistry, vol. 137, 2012. pp. 5011–5017.
16. Kirchner N., Furukawa T. Infrared Localisation for Indoor UAVs. 1st International Conference on Sensing Technology, 2005, pp. 60-65.
17. Hagisonic StarGazer Robot Localization System [online] [09.03.2014]. Available at: http://www.robotshop.com/ca/en/hagisonic-stargazer-localization-system.html#description
18. Oh J.H., Kim D., Lee B.H. An Indoor Localization System for Mobile Robots Using an Active Infrared Positioning Sensor. Journal of Industrial and Intelligent Information, vol. 2(1), 2014, pp. 35-38.
19. Estaves J.S., Carvalho A., Couto C. Generalized Geometric Triangulation Algorithm for Mobile Robot Absolute Self-Localization. IEEE International Symposium on Industrial Electronics, vol. 1, 2003, pp. 346 – 351.
20. Disturbance Sources. Vishay Semiconductors, Document Number: 80072, 2013, pp. 1-4.
21. TSUS5200, TSUS5201, TSUS5202. Infrared Emitting Diode, 950 nm, GaAs. Vishay Semiconductors, Document Number: 81055, 2009, pp. 1-5.
22. TSSP4038. IR Receiver Module for Light Barrier Systems. Vishay Semiconductors, Document Number: 82458, 2013, pp. 1-5.
23. Application Notes [online] [24.04.2014]. Available at: http://www.excelitas.com/downloads/app_phototransistors.pdf
24. INSTRUMENT SYSTEMS GMBH. Handbook of LED Metrology. 40 p.
25. Barna P. Fundamentals of the Infrared Physical Layer. Microchip Technology Inc., 2004, pp. 1-12.