Work-in-Progress: Using Li-Fi to control Automated Guided Vehicles. Steps towards an industrial market product.

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***Abstract*—Li-Fi (Light Fidelity) is a bidirectionnal communication technology that uses visible and infrared LEDs (Light Emitting Diodes) to send data. It has the advantage of simultaneously illuminating a space as well as sending data. Furthermore, this telecommunication solution also has the advantage of being robust against RF (Radio Frequency) interference and can be deployed in harsh and electromagnetic sensitive environments. These sensitive environments may be industrial facilities where communication systems are sometimes difficult to implement. In this paper, a concrete solution is provided to an existing telecommunication constraint in the fruit industry where some Automated Guided Vehicles (AGVs) are steered by infrared lasers to move pallets between several stations. These vehicles always perform the same operations and move on the same axis. However, this system presents an alignment constraint between the control system and the AGV. The fact that the laser has a narrow beam and the receiver a narrow reception surface forces the vehicle to be perfectly aligned at all times. In practice, this is not always the case and some vibrations lead to communication losses. In order to overcome this problem, a small-scale solution using the Li-Fi technology is presented in this work and a discussion on the steps until having a commercially available product is presented using the Manufacturing Readiness level (MRL) concept.**

***Index Terms*—Li-Fi, Visible Light Communication, Industry 4.0, AGV, Autonomous Vehicle**

I. Introduction

The example discussed in this paper corresponds to the palletiser offered by MAF RODA AGROBOTIC, which allows tasks such as receiving and delivering pallets at predefined stations [1]. This moving AGV is controlled by an infrared laser technology such as the optical data transmission ISD400 developed by Sick - Sensor Intelligence company [2]. The central controlling unit as well as the AGV are equipped with such transceivers (an equipment that possesses an emitter and a receiver) to communicate with each other. The controlling unit is usually a PLC (Programmable Logic Controller) which is a programmable digital electronic system for the control of industrial processes by sequential processing. The commands always go from the central PLC to the AGV and the AGV informs back the central PLC of its current state. To make the Figures 1 and 2 easier to read, a writing convention has been chosen in this paper. The transceiver, denoted as "Tx", will refer to the infrared equipment that is connected to the PLC, and the transceiver denoted as "Rx", will refer to the equipment connected to the AGV. Figure 2 also highlights the "Safety sensor" of the AGV (see blue box). This sensor is used to maintain the safety of any technical personnel present around the AGV. The principle of operation is as follows: the speed of the trolley decreases inversely proportionally to the distance to a possible obstacle until an emergency stop is reached when this distance is below a critical threshold value.

Figures 1 and 2 emphasise the crucial need of an alignment between Tx and Rx to build a running system. Studies suggest that industrial owners are not keen on completely replacing a system that is functional and has been in use for some time with something too new [3]. To tackle the alignment problem without modifying too much the infrastructure, Li-Fi is a good candidate to replace such infrared laser systems. The emitter being an LED, its wider beam aperture enables more freedom of movement and lifts the alignement constraint. Li-Fi is the combination of Visible Light Communication (VLC) in downlink communication and infrared communication (IRC) in uplink. The difference with the previous system is that Li-Fi uses white (visible) and infrared (invisible) LEDs in replacement of IR lasers. As the radiation pattern of the

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Fig. 1. Example of MAF RODA Palletiser in fruit industry - Downlink

Fig. 2. Example of MAF RODA Palletiser in fruit industry - Uplink

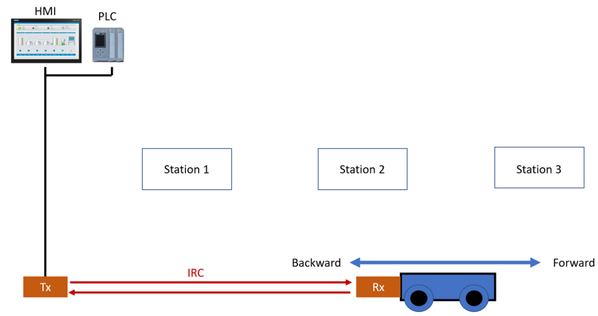

Fig. 3. General architecture of the system

optical power of LEDs is much broader than a laser, it enhances mobility flexibility under the beam of light.

This paper proposes a description of a Li-Fi system that could replace the laser communication. The rest of this paper presents the architecture of the proposed solution in comparison to the existing one. Then, a small-scale demonstrator is described and attests to the suitability of this technology. Finally, its Manufacturing Readiness Level (MRL) is discussed before concluding the paper.

II. Architecture of the AGVs Li-Fi communication solution

The general architecture of the current infrared laser communication can be observed on Figure 3 where IRC stands for infrared communication. The "Tx" is fixed on the wall as well as connected to the PLC. HMI stands for Human Machine Interface. It represents the screen the staff uses to send data and control the AGV. The "Rx" mounted on the moving trolley has the constraint of staying on the same axis as well as communicating its current state to the PLC to be displayed on the HMI of the technician. The AGV needs to always check its safety state and acknowledge that it has done what it was required of it.

The Li-Fi system takes advantage of the lighting infrastructure to be the communication medium as well. The communication from the HMI to the AGV can be done in visible light and the replies from the AGV can be send thanks to infrared LEDs as opposed to laser in the previous solution. Figure 4 shows the main differences between both technologies. The AGV under the lamp will be sure to receive commands from the HMI. This gives it more freedom of movement as long as it is within the halo of the lamp.

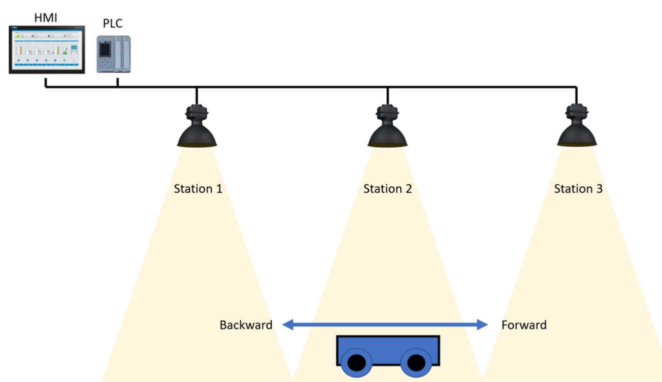

Fig. 4. General architecture of the system

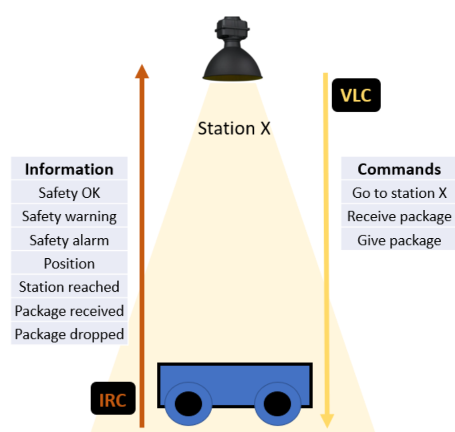

Fig. 5. Bidirectionnal communication needs of the AGV

III. SMALL SCALE PROTOTYPE

The small scale prototype uses VLC as downlink communication thanks to an open source product developed by a research institute in Spain. The infrared uplink communication is done thanks to an IRC system developed by a German research centre. Both use LEDs as types of emitters. The AGV is emulated thanks to a SunFounder PiCar-S connected to a Raspberry Pi 4 [4]. This section presents each equipment and how they were put together to demonstrate a small scale prototype.

A. Visible Light Communication

The research institute IMDEA develops opensource VLC HATs (Hardware Attached on Top) that goes on top of a BeagleBone Black (BBB) board. The HAT is the version 1.3 and is named OpenVLC1.3. The software defined PHY (Physical) and MAC (Media Access Control) layers allow a transfer data up to 400 kbit/s through the light using the UDP (User Datagram Protocol) transport protocol [5]. The BBB controlling the VLC shield is connected through USB to the central computer (which in practice should be the PLC in a large scale implementation), a Secure Shell (SSH) communication is used to communicate with the VLC system.

B. Infrared Communication

Fraunhofer IPMS (Institut für Photonische Mikrosysteme) is a German research institute that develops the “Li-Fi HotSpot Evaluation kit” capable of transmitting up to 100 Mbit/s bidirectionally in infrared [6]. The system is composed of two pairs of infrared LEDs next to infrared photodiodes. Those devices maintain high performance within a range from 0.5 meter to maximum 5 meters indoor. In this scenario, the choice of having infrared instead of white light for the uplink communication is simply in terms of eye comfort for the operators. Each transceiver needs a power source of 5 Volts and connects to the end device (the HMI in Tx and the smart car for Rx) thanks to an Ethernet cable. As this equipment is a commercial product, it is not possible to have more information about its underlying PHY and MAC protocols. The equipment is used through the Ethernet interface and behaves as a standard RJ45 cable.

C. Automated Guided Vehicle

The SunFounder PiCar-S Smart Car Kit is a smart car that works with a Raspberry Pi and rechargeable batteries. To imitate an AGV’s safety sensor like in the example taken from MAF RODA AGROBOTIC, an ultrasonic obstacle avoidance module is added to the PiCar. This module checks every 5 seconds the distance up to the nearest obstacle and the AGV adjusts its speed if the obstacle is close and/or getting closer. A Python algorithm runs on the Raspberry Pi 4 to execute the commands of the main computer (PLC in a real setup) and send back its state everytime it is needed.

IV. RESULTS

The final setup studied in this paper is constitued of two stations comprising two OpenVLC1.3 shields that are hanged 1.95 meters above the ground and 1.5 meters apart from each other. The PiCar is ordered to move from the first station to the second one or vice versa. It then acknowledges its state and gives a feedback on its safety state. Communication by visible light and infrared light were studied separately. The VLC link behaved as expected when the PiCar is located in the LEDs halos. The signal coverage depends on the optical characteristics of the openVLC LED as well as the distance between the emitter and the AGV. Greater distances mean less optical power at the photodiode side. For the uplink communication, an IRC is used for eye comfort and its unharmfulness. The wavelength of the infrared LED emitter is in the near infrared typically between 800 and 2500 nm. The infrared aperture angle is similar to that of a white LED and around 40 degrees. Figure 6 displays the setup studied.

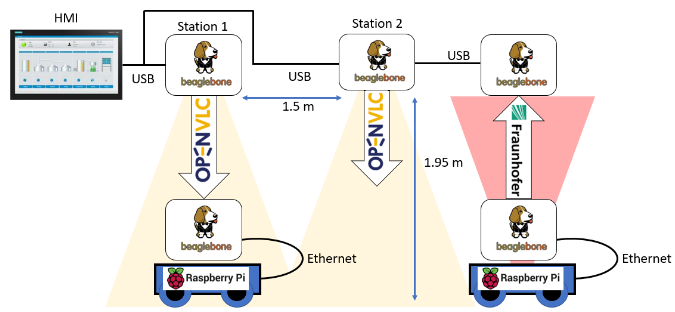

Fig. 6. VLC architecture

Initial results showed the limits of the system, the main one being the coverage of both LEDs. For the openVLC system, it showed that a radius of 0.75 meter must not be exceeded by the AGV as the communication level is not sufficient above that limit. The optical power received, measured thanks to an optical PM100D powermeter from Thorlabs, in that boundary is a level around 3.58 μW. The graphic on Figure 7 displays the optical signal power received at each increase of 10 centimeters in radius starting from the center. In parallel, the percentage of packet loss is presented. iPerf tool was used to assess a 400 kbit/s UDP link. For this prototype, a radius of 75 cm and a loss rate of 6% are considered to be the boundaries of the AGV’s functional limit. The zeros present on the graph after 0.75 meter represent non-acquired data.

The Fraunhofer equipment is a pair of transceivers with a Master/Slave configuration. The Master was chosen to be put on the AGV and the Slave on the ceiling. The communication link meets the requirements of enabling a communication link up to 100 Mbit/s at the same distances as the VLC setup. The iPerf tool is also used to assess the performance of the equipment. The average transfer bandwidth is 94.5 Mbit/s with packet sizes of 10.4 Mbytes transferred per second during a full day. Another set of tests focused on checking how much

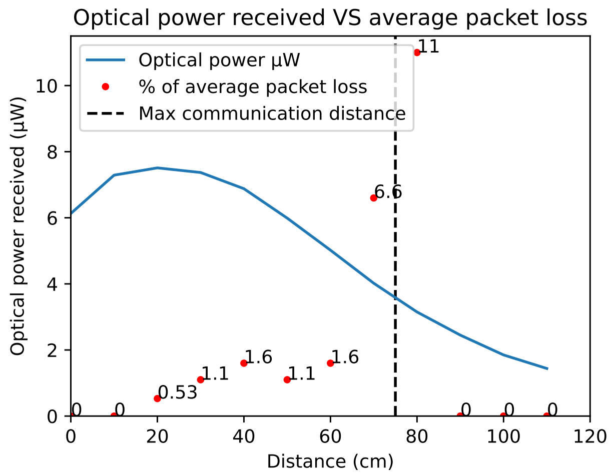

Fig. 7. Performance of the VLC link

time it takes for the link to re-establish itself after an obstruction of the emitting device. For obstructions of 5 seconds up to 30 seconds, it usually takes five seconds to re-establish the communication. It appears that the infrared communication is quite stable. It makes sense as there are less ambient disruptors in the infrared domain of wavelengths compared to the visible domain. Nevertheless, both communication links behave as excepted in presence of ambient light.

V. Manufacturing Readiness level of Li-Fi

The current state of the small-scale demonstrator presented in this paper is at the fourth stage of the Manufacturing Readiness Level represented on Figure 8 [7]. A preliminary ideation and research showed the theoretical feasibility of using Li-Fi, VLC and IRC technologies in industrial environments [8]. The previous study quantified the coverage of an industrial lamp large scale but in simulations. Results showed that about 9 m^2 per light per station can be covered. Giving AGVs more freedom than 3 meters of distance between the PLC laser transceiver and the AGV's. This step also attested, alongside the results presented here, the relevance of Li-Fi in industry and therefore constitutes a validation step.

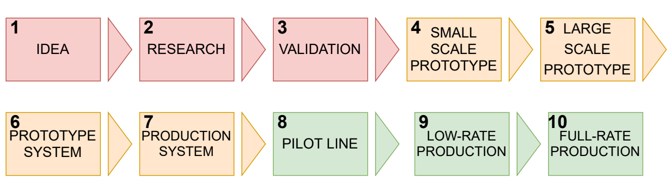

Fig. 8. Manufacturing Readiness Level

The next step in this work will be a large scale prototype and discussions are being carried out to find the most representative place of an industrial warehouse using AGVs. For now, Li-Fi products are mainly available for private consumers and indoor office spaces. Companies such as PureLiFi, OLEDCOMM, and Signify, to cite a few, produce bidirectional communication systems in VLC, IRC and Li-Fi. In order to implement an actual industrial setup, a study of the zone to cover must be realised as well as the type of emitter must be changed to typical industrial LED lights. Hopefully, the works in this paper will soon fully demonstrate the use of Li-Fi on production lines when the technology will reach its maturity.

VI. Conclusion

This paper demonstrates the feasibility and relevance of Li-Fi solutions in the industry sectors where infrared laser communications are used. A small scale prototype mimicking an industrial Automated Guided Vehicles palletiser showed great promises. This system tackles the alignment constraint of infrared laser communications that are currently used in some industrial AGVs. It also shows the progress to be made until an industrial market product is available. On the Manufacturing Readiness Level, the critical ideation, research and validation have been carried out in previous and the current work. This paper represents the small scale prototype and hopefully, a large scale prototype will soon be at the disposal of industrial production lines. The key advantage of Li-Fi in general is the use of broad LED beams to send data and thus provides an electromagnetic-free system as well as a robust system in harsh environments.

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