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Diagramación interior y tapa: Fabián Luzi

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Preface

This volume includes the articles presented at the "Xth International Conference of Production Research-Americas" (ICPR-Americas 2020), held virtually from Bahía Blanca, Argentina from December 9 to 11, 2020. This conference was organized by the local organizing committee of the city of Bahía Blanca and was sponsored by the *International Foundation of Production Research* (IFPR). This conference aims at exchanging experiences and encouraging collaborative work among researchers and practitioners from the Americas and the Caribbean region.

The first ICPR Americas conference, took place in November 2002 in Saint Louis, Missouri, USA under the general theme of "Production Research and Computational Intelligence for Designing and Operating Complex Global Production Systems". This conference generated very positive responses from the attendees. From then on, the ICPR regional meeting was held at alternate years. The second version of the ICPR-Americas was held in August 2004 in Santiago, Chile with the conference theme "Information and Communication Technologies for Collaborative Operations Management". The third edition of the ICPR-Americas held in Curitiba, Brazil, had the general theme of "Rethinking Operation Systems: New Roles of Technology, Strategy and Organization in the America's Integration Era". This instance sought to promote a deep discussion about the role of Production Engineering in the America's integration process. In 2008, the venue of ICPR-Americas was Sao Paulo, Brazil at the Universidade de Sao Paulo Campus. The conference had the theme "The Role of Emerging Economies in the Future of Global Production: Creating New Multinationals". Bogota, Colombia hosted in 2010 the fifth conference with the subject "Technologies in Logistics and Manufacturing for Small and Medium Enterprises". The sixth edition (2012) was organized around the topic "Production Research in Americas Region: Agenda for the Next Decade" by the University of Santiago de Chile in Santiago. In Lima, Peru, the 2014 edition of ICPR-Americas addressed the general theme of "Towards Sustainable Eco-Industrialization through Applied Knowledge.". The eight edition was held at Valparaíso, Chile in 2016, and more recently, in 2018, the ninth conference was held at Bogotá, Colombia under the topic „Improving Supply Chain Management through Sustainability"

ICPR-Americas 2020 was the first edition carried out in virtual mode, due to the COVID-19 pandemic. Thanks to the participation and commitment of the attendees, the conference was carried out successfully, allowing many young researchers to participate in an international conference, in a year in which these opportunities were scarce. The ICPR-Americas meeting space gave them the opportunity to share their work, as well as exchange ideas and points of view, all in the cordial atmosphere that characterizes the ICPR-Americas conferences.

ICPR-Americas 2020 was organized by a local committee of the National University of the South, supported by the university and IFPR.

The conference received more than 280 papers, of which 245 were accepted and presented during the conference. The nationality of the authors was representative of the vast

majority of the countries of America, not only South America, but also Central and North America. Something that enriched the international experience that each of the participants took from the conference.

A couple of events associated with ICPR-Americas 2020 were also held: the “SIMPOSIO INDUSTRIAL” and the “SEMINARIO de ENSAYOS ESTUDIANTILES”. Both events allowed to broaden the scope and attendance of the conference. The accepted and presented works of both events are compiled within this volume.

Finally, it only remains for us to thank the National University of the South, especially the Departments of Engineering and Mathematics, as well as the General Secretariat of Science and Technology, for the support provided to carry out the event.

March 2021

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ÍNDICE

SPECIAL SESSION: INDUSTRY 4.0

SPECIAL SESSION: **HEALTH**

SPECIAL SESSION: **FOOD**

SPECIAL SESSION: **MANAGEMENT**

Minimizing total implementation cost of a 2-D indoor localization system with a constant accuracy for underground mine tunnels

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Abstract. In this paper, we introduce the problem of minimizing total implementation cost of a 2-D indoor localization system for underground mine tunnels, guaranteeing a constant accuracy. To address this problem, we propose a system based on Cell-ID technique and visible light communication (VLC) technology with square panels of light-emitting diode (LED) lights, which fixes the maximum position error in each cell by considering the distribution of overlapping and non-overlapping cells. Formally, our system is mainly defined by an easy-to-implement algorithm based on a simple order rule. In order to illustrate the usefulness of the proposal, an example is provided. Finally, potential applications in the industrial environments are discussed and future research is proposed.

Keywords: Visible light communication, Indoor localization system, Accuracy, Cost minimization.

1 Introduction

In the last decade, visible light communication (VLC) systems for positioning has gained the attention of researchers due to its merits in terms of accuracy, cost, safety, and reliability for indoor environments [13]. Several works are related to channel design models [10, 8], while others researches assessed signal propagation and interference mitigation [11]. Most of researches related to the physical design of VLC [15, 5, 12] seeks to improve the system accuracy, considering accuracy as a result of the optimized location of the LED lights. Nevertheless, the research carried out by [6] seeks to determine the distribution of circular light-emitting diode (LED) lamps, mounted on the ceiling, in order to provide a 1-D linear positioning system with a constant accuracy along the tunnel. This perspective has large advantages in order to improve safety in mining operations.

Complementary to the previous works in this field, our research integrates the cost and 2-D positioning systems with overlapping and non-overlapping cells,

which allows to explore Cell-ID technique and VLC applications with square panels of LED light in larger mining tunnels.

2 Description of the indoor positioning system

2.1 General overview

We introduce the problem of minimizing total implementation cost of a 2-D indoor localization system with a constant accuracy. Consider underground mine tunnels, where the location is determined into the two coordinate axis (along the tunnel). In this scenario, we assume a 2-D indoor localization system based on Cell-ID technique and VLC technology. A practical implementation of Cell-ID and VLC technology is detailed in [6]. An unique code is assigned to each cell, in order to identify the lamp location. Each LED device is identical and produces a square illumination pattern subject to the used beam angle, which constraints on the minimum and maximum lighting area at the floor level and the position defined by it. Considering that the calculation of the accuracy depends on the amount of error present in the localization [16], several areas could be not necessary covered with a specific and constant error at minimal cost by using the same size of squares LED device.

To face this situation, a solution alternative emerges from the distribution of overlapping and non-overlapping cells. Some similarities with other problems in the family of *packing* are found. Considering the overlapping condition, our problem is close to the *three-dimensional bin packing problem* [9] and the *container loading problem* [3]. However, the most of these problems on 2D do not allow the overlapping elements to be positioned [7]. In addition, these problems consider the number of elements (or boxes) and their dimensions as parameters, no decision variables, with the goal of minimizing the free space [4]. Therefore, the results do not necessarily have to completely cover the surface.

To address our problem, without loss of generality we consider a rectangular area of sides a and b, $a \leq b$.

In the case of non-overlapping cells, a LED device produces a square illumination pattern of side ℓ with a maximum distance error δ between the real and estimated positions. This above value is expressed by $\delta = \frac{\ell\sqrt{2}}{2}$. Then, the projection of nine LED lamps has a coverage area of $(3\ell)^2$. Without loss of generality, we fix the maximum distance error $\delta = \frac{\sqrt{2}}{2}$, with $\ell = 1$. A VLC positioning system projection of nine square LED lamps in a rectangular area with $b = a$ with non-overlapping cells is illustrated in Fig. 1.

To consider the case of overlapping cells, we introduce the concept of *complete cell* as follows:

Definition 1. *A complete cell is a set of equal overlapping cells that defines a maximum distance error $\delta = \frac{\sqrt{2}}{2}$ independent of the number of cell identification codes received.*

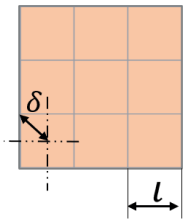

Fig. 1: VLC positioning system projection of nine square LED lamps with non-overlapping cells.

Fig. 2 illustrates a scenario with a complete cell with four overlapping cells of side $\ell = 2$, assuming equal distance between LEDs and identical beam angles. In this case, the mobile node estimated position will depend on the number of identification binary codes received from each cell and the maximum distance error δ between the real and estimated positions still remain the same, as it is depicted in Fig. 1.

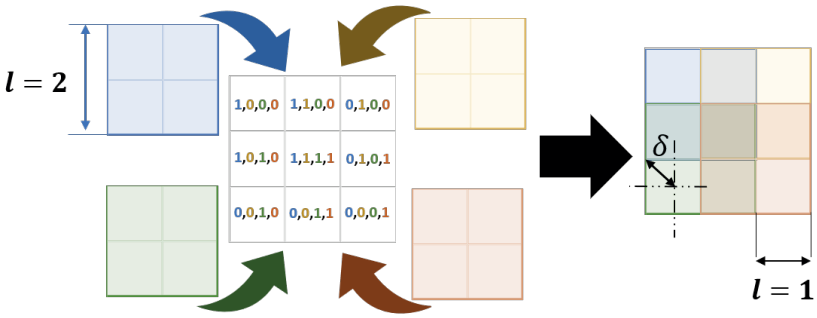

Fig. 2: VLC positioning system with a complete cell defined by four overlapping cells. The binary number with colors represents the possible cell identification codes received.

Theorem 1. *Consider a positive integer number ℓ. A complete cell the side $2 \cdot \ell - 1$, requires a set of ℓ^2 equal overlapping cells of side ℓ.*

The proof is based on geometric Euclidean analysis. The detail is omitted by space constraint.

From these above results, we propose a easy-to-implement algorithm in the next section.

2.2 Algorithm

Let α_ℓ be the cost of a unit cell of side ℓ, $\ell \geq 1$. First, we obtain a feasible solution for the rectangular area $a \cdot b$ by a number $a \cdot b$ of non-overlapping cells of side $\ell = 1$ with a total implementation cost equal to $a \cdot b \cdot c_1$. The previous value represents an upper bound for the objective value of the problem. Second, we compute the complete cell of maximum side $\ell_{\max}$ and the maximum number of each feasible complete cell β_ℓ defined by cells of side $\ell \leq \ell_{\max}$, comparing the implementation cost of a complete cell defined by cells of side ℓ and the non-overlapping cells of side $\ell = 1$ subject to the same coverage area. Finally, the algorithm considers a simple rule defined by the decreasing cost order $(2 \cdot \ell - 1)^2 / \left(\ell^2 \cdot \alpha_\ell\right)$, locating the cells configuration according to it when possible, and completing the remaining area with non-overlapping cells of side $\ell = 1$.

3 An illustrative example

Table 1 shows the parameters considered for an illustrative example, considering a rectangular area.

Table 1: Illustrative example parameters.

Rectangular area	sides	a=10	b=20		
	area	200			

Unit cell side (ℓ)	1	2	3	4	5
Unit cell cost (α_ℓ)	3.00	5.63	8.85	6.13	12.96
Complete cell side $(2 \cdot \ell - 1)$	1	3	5	7	9
Complete cell cost $(\ell^2 \cdot \alpha_\ell)$	3.0	22.5	79.7	98.1	324.0

The initial feasible solution is given by 200 unit cells of side $\ell = 1$ with a total implementation cost equal to 600. Finally, Figure 3 represents the solution obtained by the easy-to-implement algorithm, where the gray squares corresponds to unit cells that define the complete cells. This solution is optimal.

4 Conclusions

This article introduced the problem to minimize the total implementation cost of a 2-D indoor localization system based on Cell-ID technique and VLC technology for underground mine tunnels, guaranteeing a constant accuracy. The system is based on easy-to-implement algorithm based on simple order rule. The usefulness of the proposal is illustrated by an example.

From the obtain results, the benefits of our proposal for transmitting positional information about elements within indoor scenario could be extended

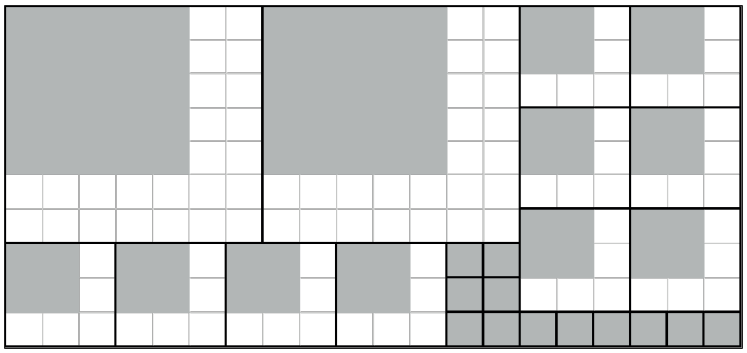

Fig. 3: Optimal VLC positioning system with overlapping and non-overlapping cells for the illustration example. The total implementation cost is equal to 457.3. The number of the considered complete cells defined by the overlapped unit cells of side ℓ equal to 5 and 2; are 2 and 11 respectively. The remaining space is completed with 12 unit cells of side $\ell = 1$.

to the industrial environment, in particular to conceive and design warehouse management systems (WMS), one of the central links in any supply chain [14]. In these systems, the part traceability control is based on detection by RFID systems or manual picking performed by operators with barcode reading devices [1]. However, it can lead to somewhat limited information on the real-time positioning of parts or inventory items. That is, once an item has been removed from its shelf (or rack) and is moved to another location, we only have information about the item being removed, and not about the evolution or path of that item. If there is movement control, it is on the carrier of the element [2]. Thus, our proposal would greatly improve the availability of information, with an easier implementation since it is directly linked to the lighting system.

Finally, future research work could be focused on the formulation of mathematical models and algorithms in order to obtain optimal or approximate solutions for the problem.

References

1. A. M. Atieh, H. Kaylani, Y. Al-abdallat, A. Qaderi, L. Ghoul, L. Jaradat, and I. Hdairis. Performance improvement of inventory management system processes by an automated warehouse management system. *Procedia Cirp*, 41:568–572, 2016.
2. G. Fragapane, D. Ivanov, M. Peron, F. Sgarbossa, and J. O. Strandhagen. Increasing flexibility and productivity in industry 4.0 production networks with autonomous mobile robots and smart intralogistics. *Annals of operations research*, pages 1–19, 2020.
3. J. A. George and D. F. Robinson. A heuristic for packing boxes into a container. *Computers & Operations Research*, 7(3):147–156, 1980.
4. S. Hougardy. On packing squares into a rectangle. *Computational Geometry*, 44(8):456–463, 2011.

5. D. Iturralde, F. Seguel, I. Soto, C. Azurdia, and S. Khan. A new VLC system for localization in underground mining tunnels. *IEEE Latin America Transactions*, 15(4):581–587, apr 2017.
6. N. Krommenacker, Ó. C. Vásquez, M. D. Alfaro, and I. Soto. A self-adaptive cell-ID positioning system based on visible light communications in underground mines. *2016 IEEE International Conference on Automatica, ICA-ACCA 2016*, 2016.
7. A. Lodi, S. Martello, and D. Vigo. Approximation algorithms for the oriented two-dimensional bin packing problem. *European Journal of Operational Research*, 112(1):158–166, 1999.
8. I. Mansour. Effective Visible Light Communication System for Underground Mining Industry. 8(2):331–339, 2020.
9. S. Martello, D. Pisinger, and D. Vigo. The three-dimensional bin packing problem. *Operations research*, 48(2):256–267, 2000.
10. F. Miramirkhani and M. Uysal. Channel modelling for indoor visible light communications. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 378(2169):20190187, apr 2020.
11. P. Palacios Játiva, C. A. Azurdia-Meza, M. Román Cañizares, D. Zabala-Blanco, and C. Saavedra. Propagation Features of Visible Light Communication in Underground Mining Environments. pages 82–93. 2020.
12. F. Seguel. *Robust localization system using Visible Light Communication technology for underground mines*. PhD thesis, Université de Lorraine; Universidad de Santiago de Chile, 2020.
13. I. Soto, R. N. Rodrigues, G. Massuyama, F. Seguel, P. P. Játiva, C. A. Azurdia-Meza, and N. Krommenacker. A hybrid VLC-RF portable phasor measurement unit for deep tunnels. *Sensors (Switzerland)*, 20(3):1–17, 2020.
14. J. P. Van den Berg and W. H. Zijm. Models for warehouse management: Classification and examples. *International journal of production economics*, 59(1-3):519–528, 1999.
15. S.-H. Yang, H.-S. Kim, Y.-H. Son, and S.-K. Han. Three-dimensional visible light indoor localization using aoa and rss with multiple optical receivers. *J. Lightwave Technol.*, 32(14):2480–2485, Jul 2014.
16. M. T. Zia. Visible light communication based indoor positioning system. *TEM Journal*, 9(1):30–36, 2020.