A Simultaneous Obstacle and Inclination Detection for Macao World Heritage District Photovoltaic Systems Based on GIS and UHF RFID

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***Abstract*— This paper presents a novel obstacle and inclination detection technique for Macao world heritage district photovoltaic system using Geographical Information System (GIS) – Google Earth and 920-MHz Ultra-High Frequency Radio Frequency Identification (UHF RFID). For larger solar energy capacity required in heritage protection and development, the vertical solar panel attached to the building wall is considered; the solar panel is tagged with a UHF RFID tag with a transparent 3D hollow substrate. Its tag antenna effective area can be significantly affected if an obstacle is placed between the tag and reader. The 3D hollow substrate is filled with liquid; the liquid flows with panel inclination establishing a perfect conductor plate (PEC) for the tag antenna. Such PEC disables the tag operation, allowing a vertical solar panel inclination safety detection in operation. An experimental trial of the tag's Received Signal Strength Index (RSSI) reports more than 10 dB difference with and without obstacles. The inclination safety with 20 degrees deviated from 90-degree normal installation is verified by RSSI change from -67 dBm to -85 dBm. This property is a simple and economical solution for photovoltaic systems to detect obstacle shadowing or covering the solar panel; efficient inclination safety can be easily integrated.**

Keywords — Macao World Heritage, GIS, RFID, RSSI.

I. INTRODUCTION

Due to the land limit, a shortage of renewable energy for World Heritage Tourism in small cities risks fueling sustainability. For example, Macao is a former Portuguese colony in China with abundant Portuguese-Chinese tourism resources and a land area of 32.9 km^2. In such a tiny city, old buildings along narrow streets to heritage sites overflowing with day and night entertainments, cafes, and souvenir shops are essential to Macao's long-term tourism sustainability. In addition to high population density, the historic urban area's advancement of electricity substitution in energy consumption and electricity demand is highly required. Innovative energy-saving facilities, such as various forms of wind power, coated glass, and photovoltaic solar energy, have been used to cut electricity demand. This technology has been used for years in places like Europe, as shown in Fig. 1, where architectural and planning requirements for historically protected buildings create considerable technical challenges in incorporating renewable energy sources like photovoltaics [1]. According to the Strategic Energy Technology Plan, renewable technologies are at the heart of the new energy system, with photovoltaic solar energy as the fundamental pillar [2]. Cristina S. Polo Lópeza and Francesco Frontinia also presented a few instances of solar panels in windows, balconies, terraces, and tilted roofs, as well as a few renewable solar energy choices for historic houses [3]. However, the expansion of the traditional electricity supply has been subject to many restrictions due to heritage protection, which is indeed a dilemma.

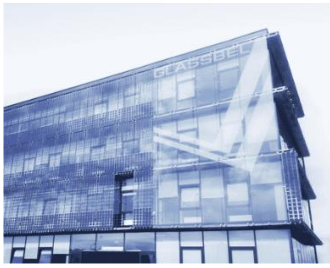


Fig. 1. Examples of Photovoltaic System Implementation in Building Façade

Solar energy can potentially maintain and conserve World Heritage sites [4-5]. For a location like Macao, where the population density is high, and people live in high-rise buildings, the available rooftop area for solar power to meet local energy demand that is limited by the land size. As a result, building façades provide a visually appealing and complimentary choice [6]. To this end, we analyze the use of a photovoltaic system integrated into a façade and mounted on top of an existing or newly constructed façade, or even integrated into an existing façade solution [7], which results in modernizing and making them energy efficient [8], with a capacity that can be increased by 3-5 times. However, such as solar panel collisions and barrier coverage may pose concerns. To this end, this research provides a cost-effective UHF RFID solution based on GIS and UHF RFID to detect obstruction and inclination change. As shown in Fig. 2, a vertical solar panel is mounted to a building wall and is tagged with a UHF RFID tag on a transparent 3D hollow substrate. If there is an obstruction between the tag and the reader, the effective area of the tag antenna is significantly reduced in addition to the inclination.

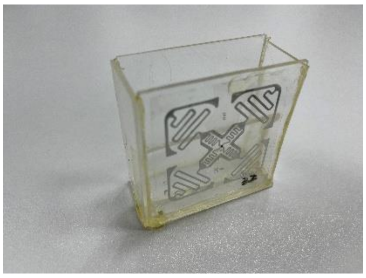


Fig. 2. UHF RFID Tag with 3D Hollow Substrate

II. UHF RFID Obstacle and inclination Detection

As illustrated in Fig. 3, an RFID system operating at UHF uses a half-duplex form of backscattering transmission. The forward link transmits energy-carrying waves to UHF tags. The return link receives the signal from the UHF tag to the reader.

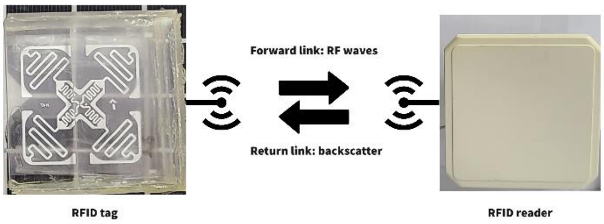


Fig. 3. Principle of Backscattering

After receiving the response, the reader calculates and analyzes the signal's Received signal strength indication (RSSI) in decibels. RSSI is a metric for determining the strength of the power received from an RFID tag's returned signal. RSSI has a normal range of -30 dBm to -85 dBm. It refers to how well each tag reacts to the reader. If the tags are not obstructed, the reader broadcasts a higher RF wave energy with a higher RSSI while using backscattering mode in UHF passive tags. Because the sent signal becomes weaker when some material separation or impediments are placed between tag and reader, the RSSI will be decreased. This simple method enables several cost-effective solutions for existing buildings, such as obstacle shadowing and covering detection. The power gathered by a tag is proportional to the receiving area of the tag antenna, and an obstruction might have a considerable impact on the power received by the tag. In actuality, the tag's antenna A_e's effective receiving area is provided by

$$A_e = \frac{\lambda^2}{4\pi} G_{Tag} \quad (1)$$

where is the electric length of the operating frequency, and GTag is the antenna gain. In the following part, we will look at different RSSI variations of the obstacle effect between tags and readers.

The system in Fig. 4 is our proposed integrated UHF RFID and photovoltaic system to identify angles of change, obstructions, and solar system orientation based on changes in environmental parameters. Due to their size and ease of integration, photovoltaic cells are equipped with UHF RFID tags. Signal variations between tags and readers could be used to add a basic detecting function to the existing solar system. [9-10]

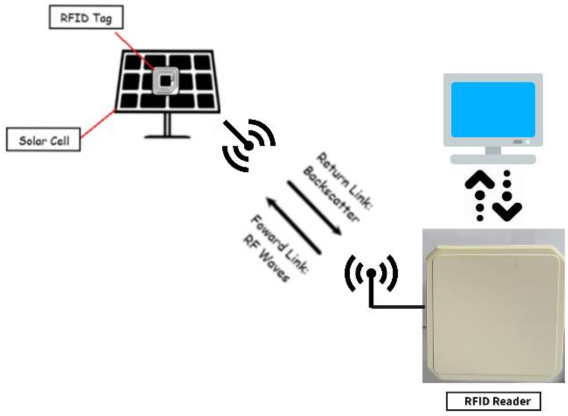


Fig. 4. Schematic Representation of the Integrated Sensing of UHF RFID and Photovoltaic System

III. Solar Radiation Estimation in GIS Platform

In the same way as the introduction, an example heritage area in Macao – St. Anthony's Church – is discussed in Fig. 5, with three potential sites highlighted as Buildings #1 to #3. This church, made of bamboo and wood before 1560 and one of Macao's oldest churches, is also the site of the Jesuits' initial headquarters in the city. The current style and size date from 1930, and the church has been restored in stone several times. Previously, members of the Portuguese community celebrated wedding customs there. According to Google Earth Pro, these three rooftop surfaces are estimated to be 150 m^2, 250 m^2, and 350 m^2 respectively, whereas the building façade areas are 3-5 times larger. Using this GIS application, we may successfully determine the façade area as a supplementary study of solar energy obtained by vertical solar panels. As shown in Fig. 6, building #1 and Building#2 are studied with Google Earth Pro, the respective areas are 150 m^2 and 250 m^2 for horizontal area, and 602 m^2 and 800 m^2 for façade of building#1 and building#2.

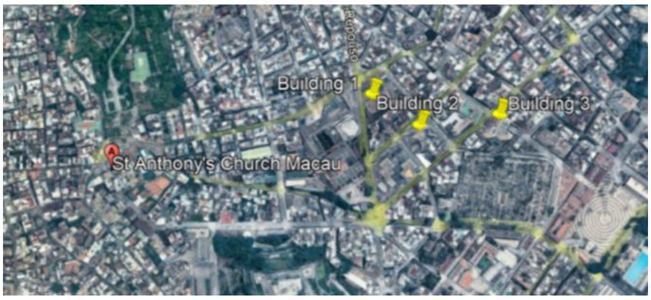
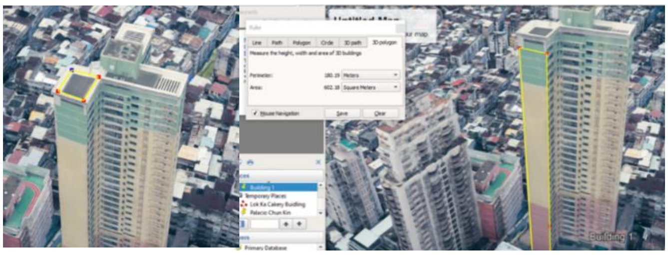
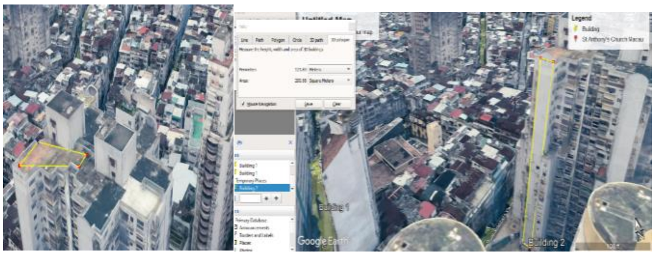


Fig. 5. World Heritage District of St. Anthony's Church



(a) Building#1



(b) Building#2

Fig. 6 Available Area Comparison Between Rooftop and Façade (a)-(b)

IV. EXPERIMENTAL RESULTS

The RFID tag with a 3D hollow substrate was inserted in the Photovoltaic cell 1 m from the reader for the experiment depicted in Fig. 6. RSSI is -66 dBm, according to the measurement. The RSSI is -48 dBm without the obstacle. The RSSI change clearly shows us the difference between when there is an impediment and when there is not. We can detect the presence of a barrier using this behavior. The tag's Received Signal Strength Index (RSSI) experimental trial reports more than a 10 dB difference with and without obstacles.

Fig. 6. Detection Experiment Setup

The inclination safety with 20 degrees deviated from 90-degree normal installation is verified by RSSI change from -40 dBm to -80 dBm. As shown in Fig.8. for the distance between reader and the tag of 70 cm, the RSSI changes from -67dBm to -81dBm when the inclination of solar panel is varied from 90-degree to 30-degree; for the distance between reader and the tag of 80 cm, the RSSI changes from -75 dBm to -81dBm when the inclination of solar panel is varied from 90-degree to 30-degree; for the distance between reader and the tag of 100 cm, the RSSI changes from -80 dBm to -85dBm (undetectable) when the inclination of solar panel is varied from 90-degree to 30-degree. This is a simple and economical solution for the photovoltaic system for mounting on the vertical building façades to detect obstacle shadowing or covering the solar panel; efficient inclination safety can be easily integrated with the combination of RIFD tags and photovoltaic systems.

V. CONCLUSION

In this paper, RFID sensors can be used in modern Smart Buildings to detect structural status, including the Photovoltaic system of World Heritage. The distributed Solar Photovoltaic System is also widely used in buildings, and its structural status and information like orientation, obstacles etc., are essential for the operation and efficiency of a Photovoltaic system. This work presents an economical 3D printed UHF RFID and GIS solution for vertical solar panel status detection for wireless monitoring of structural status and information that benefits the development of World Heritage protection.

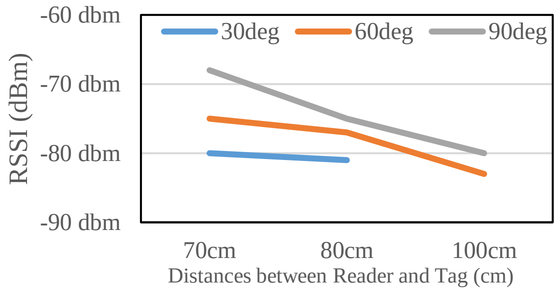


Fig. 8. Measurement result of the Positioning-Angle Variation Experiment

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REFERENCES

[1] Rosa, Flavio. "Building-Integrated Photovoltaics (BIPV) in Historical Buildings: Opportunities and Constraints." Energies, vol. 13, no. 14, July 2020, p. 3628. DOI.org (Crossref), doi:10.3390/en13143628.

[2] SET-Plan TWP PV Implementation PlanFinal Draft. 2017. Available online: https://setis.ec.europa.eu/system/files/set_plan_pv_implmentation_plan.pdf (accessed on 15 January 2020). Transactions on Industrial Electronics, vol. 57, n. 7, pp. 2492-2498, 2010.

[3] C. S. Polo López and F. Frontini, "Energy efficiency and renewable solar energy integration in heritage historic buildings," Energy Procedia 48, pp. 1493 – 1502, 2014.

[4] Bandarin, F.; Van Oers, R. (Eds.) Reconnecting the City: The Historic Urban Landscape Approach and the Future of Urban Heritage; Wiley-Blackwell: Oxford, UK, 2014. 8. Veldpaus, L.; Pereira Roders, A.;

[5] Colenbrander, B.J.F. Urban Heritage: Putting the Past into the Future. Hist. Environ. 2013, 4, 18–33.

[6] M.C. Brito, S. Freitas*, S. Guimar~aes, C. Catita, P. Redweik "The importance of façades for the solar PV potential of a Mediterranean city using LiDAR data" Renewable Energy 111 (2017) 85-94.

[7] Daniel Chemisana, Building integrated concentrating photovoltaics: a review, Renew. Sustain. Energy Rev. 15 (1) (January 2011) 603e611, http://dx.doi.org/

[8] R. Rüther, M.M. Dacoregio, Performance assessment of a 2 kWp grid-connected, building-integrated, amorphous silicon photovoltaic installation in Brazil, Progress in Photovoltaics: Research and Applications, vol. 8, pp. 257–266, 2000.

[9] Taeyon Hwang, Seokyoun Kang, Jeong Tai Kim, Optimization of the building integrated photovoltaic system in office buildings—Focus on the orientation, inclined angle and installed area, Energy and Buildings, vol. 46, pp. 92–104, 2012.

[10] R. Wang, O. T. Tai and K. W. Tam, "Solar Radiation Reduction Monitoring of Macao World Heritage District Photovoltaic System Using GIS and UHF RFID Obstacle Detection Approach," 2021 9th International Conference on Smart Grid (icSmartGrid), 2021, pp. 154- 157, doi: 10.1109/icSmartGrid52357.2021.9551216.