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Remote identification of research and educational activities using spectral properties of nighttime light

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ABSTRACT

Research and educational activities (R&EAs) are major forces behind modern economic growth. However, data on geographic location of such activities are often poorly reported. According to our research hypothesis, intensities and spectral properties of artificial light-at-night (ALAN) can be used for remote identification of R&EAs, due to their unique ALAN signatures. In order to develop activity identification models, we carried out a series of *in situ* measurements of ALAN intensities and spectral properties in a major metropolitan area in Israel. For this task, we used an illuminance CL-500A spectrophotometer that measures the total intensity and spectral irradiance of ALAN, incremented by a 1-nm pitch, from 360 to 780 nm. As our analysis shows, logistic regressions, incorporating ALAN intensities at the peak or near-peak wavelengths, and geographical attributes of the measurement sites as controls, succeeded to predict correctly up to 98.6% of the actual locations of R&EAs. A digital camera satellite image, obtained from the Astronaut Photography Database, was used for the model's validation. According to the validation results, the actual locations of R&EAs coincided well with the estimated high probability areas, as confirmed by the values of Cohen's Kappa index of up to 64%, which indicate a reasonable level of agreement.

1. Introduction

Research and educational activities (R&EAs), formed by universities, colleges and research centers, belong to the *quaternary* economic sector, which is the most innovative and knowledge-based sector of national economies (Selstad, 1990; Peneder et al., 2003). The contribution of this sector to modern economic growth is well established (Yusuf and Nabeshima, 2007; Acs et al., 2013).

Several empirical approaches are used in urban and regional studies to identify geographic concentrations of R&EAs. One of these approaches is based on patents, innovation or publication counts, and human capital indices, serving as proxies (Acs et al., 2002; Toutkoushian et al., 2003; Crescenzi et al., 2012; Capello and Lenzi, 2013). However, a major difficulty associated with this approach is data availability, considering that most data sources on human capital and local innovation activities are available for relatively coarse geographic units, such as countries and regions (Acs et al., 2002). Moreover, differences in patent policies and innovation/publication counting also exist (Mankiw et al., 1992; Murphy and Siedschlag, 2011; Archibugi and Coco, 2004; Jaffe, 2000; Schofer and Meyer, 2005).

Alternatively, freely available satellite data on artificial light-at-night (ALAN), covering the entire earth, may help to identify R&EA geographic concentrations. In the past years, data on ALAN intensities were used in health studies (Kloog et al., 2007, 2009, 2010), demographic analysis (see *inter alia* Elvidge et al., 1997, 2001; Imhoff et al., 1997; Sutton et al., 2001; Anderson et al., 2010), regional economic performance studies (see *inter alia* Elvidge et al., 1997; Doll et al., 2000; Sutton et al., 2007; Henderson et al., 2009; Ghosh et al., 2010; Chen and Nordhaus, 2010; Kulkarni et al., 2011; Zhao et al., 2011; Mellander et al., 2013), as well as for human footprint analysis (Yang et al., 2014; Alamús et al., 2017). Several studies also explored the association between ALAN and local concentrations of economic activities (EAs), either generalized (Ebener et al., 2005; Doll et al., 2006; Bhandari and Roychowdhury, 2011; Xiangdi et al., 2012) or industry-specific (Rybnikova and Portnov, 2014, 2015).

In addition to differences in ALAN intensities, different sources of ALAN, such as incandescent lamps, halogen lamps, fluorescent lamps, halide lamps, and high pressure sodium lamps, emit light

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of *different spectral properties* (Elvidge and Keith, 2009). However, to the best of our knowledge, *spectral properties* of ALAN have not been used to date as a remote identification tool and their potential for remote identification of on-ground EAs is largely unknown.

The present study aims to explore the potential of using ALAN spectral properties for the remote identification of on-ground EAs, using R&EAs as a test case.

Facility managers may choose their lighting strategies, based on energy efficiency and lighting quality considerations (ALG, 2016), or considering how lighting conditions may affect health, well-being and task performance (Veitch et al., 2008) or to attract more customers by increasing visibility of their businesses from far away after the natural dusk (Johnstone, 2009). For instance, hospitals or gas stations may choose light of bright white colors to draw people's attention. As for universities and research institutions, their activities after the natural dusk are often quite slow, primary concentrated indoor, and not much advertising is needed. As a result, universities and research institutions may save on outdoor illumination by using light sources of low intensity and of warm colors, without harming their performance.

The rest of the paper is organized as follows. We start by describing our study methods and data sources, report modelling results and discuss study limitations and prospects for future research.

2. Research methods

The rationale behind the use of ALAN for remote identification of specific EAs is that ALAN differs by its intensity and its spectrum properties, depending on its source (Elvidge and Keith, 2009), and that different types of land uses and EAs often use ALAN sources of different type and intensity, best fitted their resources and needs (Singh, 2006). As a result, ALAN *levels and spectral properties* (that is, the distribution of light intensities across different parts of the overall light spectrum) can become a marker for specific EAs, which cannot be accessed on the ground or information on which is limited due to poor reporting.

2.1. Research goal and objectives

The goal of this study is to determine whether the combination of ALAN intensities and spectral properties can serve as a *marker for R&EAs*, helping to differentiate them remotely from other EAs and land uses.

Our specific objectives are as follows:

- To determine whether R&EAs differ significantly from other EAs in terms of intensities and light spectrum properties they emit.
- To develop and validate the ALAN-based model for R&EA identification.

2.2. Study area and data sources

The present study was carried out in the Greater Haifa Metropolitan Area (GHMA), which is the third largest metropolitan area in Israel (after Tel Aviv and Jerusalem). The study was performed during January–March 2015, a period of generally good weather and clear visibility. ALAN intensities, emitted at different sub-*spectra*, were measured *in situ* in different city areas, hosting R&EAs, shopping centers, restaurants, theatres, museums, hotels, parks, hospitals and industrial facilities. A total of 610 *in situ* measurements were performed, including 148 measurements carried out at 4 locations hosting major research institutions and universities (see Appendixes A and B). The measurements were taken around the buildings, at a distance of about 5–10 m from the walls and about 30–50 m from each other. Different number of measurements at different EAs sites (see Appendix A) was due to differences in the size of individual facilities.

The intensities and ALAN spectral properties were measured using the Illuminance Spectrophotometer CL-500A (KM, 2015), measuring the total irradiance (in w/m^2) and spectral irradiance (in w/m^2/nm) of light, by a 1-nm pitch, from 360 to 780 nm, roughly covering the entire visible light spectrum.

Additional socio-economic and land-use attributes, required for multivariate modelling as controls were either obtained from the Israel Central Bureau of Statistics (*viz*., percent of high school graduates and share of low income population in the neighborhood), or calculated for each measurement spot, using ArcGIS10.x™ tools. In particular, for each measurement point, we calculated its distance to the center of gravity of the city's population, using the *mean center* tool in the ArcGIS10.x™ software (ESRI, 2015a).

These socio-economic and locational variables, used in the analysis as controls, may help to explain specific locations of R&EAs due to different association mechanisms. Thus, *percentage of highly educated people in the neighborhood* may be useful because highly educated workers and university graduates often choose residential locations close to the places of their work or study (Rohlen, 1979; Cervero and Wu, 1997). In empirical studies, *average income* is also used as a general indicator of the quality of life, local productivity, *etc*. (see *inter alia* Rappaport, 2006; Ortiz and Cummins, 2011). Many R&EAs are often surrounded by vast green areas and are often located relatively far from densely populated central areas. To account for this effect, we used distance to the *center of population gravity* as an additional explanatory variable.

2.3. Statistical analysis

To estimate the magnitude of differences between the spectral distribution of ALAN emitted by R&EAs and that emitted by each of the other EA, several statistical tests were used. In particular, in the initial stage of the analysis, we compared peaks of ALAN intensities, emitted at the visible light *spectrum* by different EAs. Next, we used one-way ANOVA tests to assess the differences in ALAN intensities, emitted by different measurement spots within a given EA. We also used ANOVA to explore differences in the ALAN intensities, emitted by different EAs. Since our data did not always met the normality and homogeneity of variance assumptions, ANOVA tests were replicated by non-parametric Kruskal-Wallis tests. The goal of this analysis was to identify the wavelengths, at which a certain EA stands out in term of its ALAN emissions, and to determine the magnitude of differences between different EAs in terms of ALAN intensities and spectral properties they emit.

At the next stage of the analysis we used logistic regressions, to estimate the probability of a given EA to occur under a given set of values of explanatory variables, including ALAN spectral properties and socio-economic and land use attributes. The generic form of the model, used in the analysis, was given to the following equation:

$$\log(p/1-p) = Constant + \mathbf{b} * \mathbf{SGEO} + \mathbf{c} * \mathbf{I} + \varepsilon, \quad (1)$$

where p = probability of a given EA to occur under the settled values of predictors; **b** and **c** = vectors of coefficients of regression; **SGEO** = vector of social and geographical attributes of each ALAN measurement place, such as distance to the center of population gravity, percent of high school graduates and percent of low income population in the neighborhood; **I** = vector of ALAN intensities, emitted by R&EAs and other EAs at wavelengths of visible spectrum (i.e., from 360 to 780 nm), and ε = random error term.