

An Approach Based on Linked Open Data and Augmented Reality for Cultural Heritage Content-Based Information Retrieval

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Abstract. Nowadays, many technologies are changing our way of life, including those related to extended reality. One of the most interesting is Augmented Reality (AR). Today, even if this technology seems to be discovered yet, it is widely applied in several contexts, including the fruition and conservation of cultural heritage. Such spread is mainly offered by the new and more powerful mobile devices, allowing museums and art exhibitions to use AR to offer new experiences to visitors. In this paper, we present an augmented reality mobile system based on content-based image analysis techniques and Linked Open Data to improve the user knowledge about cultural heritage. We use different image analysis techniques, and we present several experimental results to show the performance of our system.

1 Introduction

Cultural heritage (CH) often fails to be a successful attraction because it cannot fully capture people's interests. Moreover, the enjoyment of an archaeological site cannot be improved due to legal or environmental regulations, and it is often hard to recognize relevant details in a cultural landscape or understand their meanings.

A new way of enhancing cultural sites is to provide information to users quickly and intuitively. In this context, information has a strategic value to understanding the world around a user, and new technologies provide the ability to interact with places or objects in real-time [28,29]. Furthermore, cultural heritage goes towards decay, so future generations may not be able to access many artistic works or places.

Digital cultural heritage is a set of methodology and tools that use digital technologies for understanding and preserving cultural, or natural heritage [1]. The digitisation of cultural heritage allows the fruition of artwork from literature to paintings for current and future generations.

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Augmented reality (AR) represents a technique that has changed the way of enjoying art in recent years. In this context, the advancement of information technologies has made it possible to define new ways to represent and integrate natural and digital information [15]. Augmented reality allows information to be superimposed around the user without blinding him in his physical environment. Mixed reality overlays information on the real world and includes the ability to understand and use the environment around the user to show or hide some of the digital content. Indeed, virtual reality allows users to be completely immersed in a computer-generated environment while the real world is hidden when the device is in use. Additionally, there are new classifications of the reality-virtuality continuum, such as extended reality, in which the real world and virtual world objects are presented within a single display. Thus, extended reality includes all the previously mentioned categories [48].

Most applications that extensively use multimedia objects, such as digital libraries, sensor networks, bioinformatics and e-business applications, require effective and efficient data management systems. Due to their complex and heterogeneous nature, managing, storing and retrieving multimedia objects are more demanding than traditional data management, which can be easily stored in commercial (primarily relational) database management systems [18].

A solution to the problem of retrieving multimedia objects is to associate the objects with a specific description [24,32]. This description allows us to make a retrieval by similarity. How this description occurs depends on the type of object. An image description can be done in two ways: through metadata or visual descriptors, [18]. Content-Based Image Retrieval (CBIR) is the application of computer vision to image recovery. Its goal is to limit the use of textual descriptions and develop techniques for retrieving images based on automatically extracted multimedia characteristics from a user-requested image or user-specified image features. Moreover, novel data structure as knowledge graphs [35] could combine different data to improve their informative layers [25].

In the realm of the semantic web, [3], linked data is a way of publishing structured data that allows data to be linked together. The publication of linked data is based on open web technologies and standards such as HTTP, RDF (Resource Description Framework) and URI. The purpose of this data structuring is to allow computers to read and interpret the information on the web directly. The links also make extracting data from various sources through semantic queries. When linked data links publicly accessible data, it is referred to as linked open data (LOD) [50].

In this work, CBIR techniques are used via mobile devices that retrieve information in real-time through interaction with Linked Open Data. This information is superimposed on the scene under observation and shown to the user.

The paper is organised as follows: in Sect. 2 we provide a review of the literature related to CBIR and augmented reality for cultural heritage; Sect. 3 introduces the used approach along with the general architecture of the system; in Sect. 4 a use case of the proposed system is described and discussed; in Sect. 5

we present and discuss the experimental strategy and results; lastly, Sect. 6 is devoted to conclusions and future research.

2 Related Works

The application of technology to cultural heritage is a topic that has been widely discussed. The UNESCO 1970 convention stated that the presentation work should keep pace with the progress of "communication, audiovisual techniques, automatic data processing and other appropriate technologies, as well as cultural and recreational trends" [44].

In this context, AR is considered a feasible technology for the heritage sector because it is now possible to develop applications for consumer-level mobile technology [30].

Furthermore, thanks to the AR technologies, new values can be added to CH sites [9]. Visitors can explore unfamiliar surroundings enjoyably and thrillingly [12]. Consequently, this is one of the most significant benefits from a supply perspective because many tourists are looking out for exceptional and unforgettable on-trip experiences [49]. Besides enjoyment, investigators argue that the interaction between visitors and AR systems contributes to a richer CH experience [14], demonstrating an experience co-creation, i.e. user and provider jointly produce a valued outcome [26,47].

Augmented reality has been one of the technologies that have spread most in the artistic field, and its application has been studied often and from different points of view. Diek and Jung, for example, have identified the economic, experiential, social, epistemic, cultural, historical and educational values of the greater reality in the context of cultural heritage [45].

On the other hand, content-based image retrieval has also found extensive application in the field of cultural heritage, for example, in [22] where the authors used it for e-documentation of monumental heritage and 3D reconstruction. The widespread diffusion dictated the choice to bring this type of application to mobile systems that this device has had in recent years. Most people now own a smartphone, and therefore the costs to offer this type of experience to users are very limited.

Among the many examples of augmented reality applications on mobile systems for cultural heritage, we mention [42] where the authors propose a mobile application that uses augmented reality to provide users with information on natural monuments. For example, the authors in [17,43] have used CBIR to develop an application that acquires the images from a camera to exemplify the information retrieval process. They used this information to enrich the image shown to the user. In [16] the authors introduced applications that exploit SURF and the greater reality for the visualisation of information and 3D models of cultural heritage sites. In [4,10,27,37] there are other similar examples but with applications designed for mobile systems. Other descriptors are used in digital cultural heritage applications as in [46], where the authors use ORB, a similar algorithm that is faster in extracting and comparing features. The authors in [13]

describe, together with an application that uses augmented reality and retrieval, the results of experiments conducted during some museum visits. These experiments aim to study how such a tool can transform visitors' learning experience.

An Italian example is the "Ducale" research project, which proposes ICT solutions for the Palazzo Ducale museum in Urbino. A mobile application that uses augmented reality and content-based image retrieval to enhance the museum visit experience is presented. In this project, the famous painting "Ideal City" becomes a case to exemplify a specific approach to digital mediation of cultural heritage [8].

In our work, we proposed a novel approach where the use of different descriptors is tested and used to have optimal performances in different real scene exposures using a mobile CBIR framework. Moreover, the retrieved images are integrated with Linked Open Data to retrieve textual data and give more information to users employing augmented reality.

3 The Proposed System

In this section, we detailed our system. Figure 1 shows the top-level architecture. An essential component of our system is the Multimedia Knowledge Base [31] that contains all indexed images with related external resource links, specifically with Linked Open Data (LOD). The use of visual information is an important improvement for the understanding of object meaning [40].

The system indexes the images using local features extracted with the Keypoint Detector, in our case are SIFT (Scale Invariant Feature Transform) [20], SURF (Oriented FAST and Rotated BRIEF) [2] and ORB (Oriented FAST and Rotated BRIEF) [38].

In particular, the modules that compose our architecture are:

- *Picture Loader*: it loads the pictures taken from a mobile phone;
- *keypoint Extractor*: it processes the pictures and applies a keypoint Detector to extract local descriptors;
- *keypoint Marker*: it compares the local features of input pictures with all indexed images and returns the best matching.
- *Augmenter Picture*: using a SPARQL query to retrieve the information from LOD;
- *Result Checker*: in case of wrong or missed matching, it helps the user add or select the correct matching.

In the following of this section, we detail the proposed framework with the used technologies and techniques. A keypoint Detector locates some features from an image and describes them. SIFT was proposed as invariant to rotation, affine transformations, intensity, and viewpoint change in matching features. SIFT is composed of four main steps. The first one applies the Difference of Gaussian (DoG) to estimate the scale-space extremes. The second one localities the key point removing the low contrast point. The third one assigns orientation

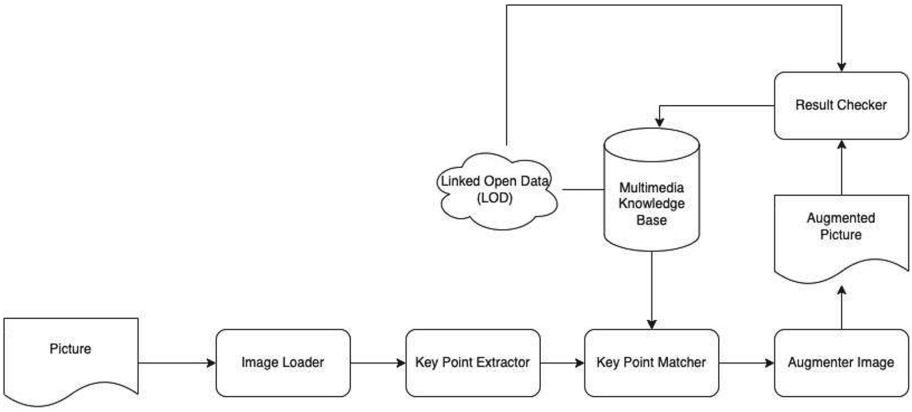


Fig. 1. System architecture

to key points using local image gradients. The last one generates a descriptor based on each keypoint image gradient magnitude and orientation.

SURF approximates the DoG with box filters. Instead of Gaussian averaging, the image uses a square to approximate the convolution because the square is faster with the integral image. SURF uses a BLOB detector based on the Hessian matrix to find the points of interest. The orientation assignment uses wavelet responses in horizontal and vertical directions by applying adequate Gaussian weights. For feature description, SURF uses wavelet responses. A neighbourhood around the key point is selected and divided into subregions, and then for each subregion, the wavelet responses are taken and represented to get the SURF feature descriptor. The sign of Laplacian which is already computed in the detection, is used for underlying interest points. The sign of the Laplacian distinguishes bright blobs on dark backgrounds from the reverse case.

ORB is a FAST keypoint detector based on a BRIEF descriptor with some modifications. Originally, to determine the key points, it used FAST. Then, it applies a Harris corner measure to find the top N points. Due to FAST does not compute the orientation and is a rotation variant, it computes the intensity weighted centroid of the patch with a located corner at the centre. The direction of the vector from this corner point to the centroid gives the orientation. Moments are computed to enhance the rotation invariance. In ORB, a rotation matrix is computed using the orientation of the patch, and then the BRIEF descriptors [5] are steered according to the orientation.

As shown in Fig. 3, the foremost step executed from the system is image acquisition, keypoint detection, image augmentation, visualisation of the result, and results checking. In this process user interacts with the system in only two cases, firstly to take a picture and lastly in case of wrong or missed matching.

In our framework, a user takes a picture using a mobile device that sends it to the server that extracts the keypoint and compares it with the indexed keypoint using the best matching techniques. Eventually, the server retrieves



(a) Keypoint detection example (b) Keyoint machining example

Fig. 2. An example on Pietà di Michelangelo

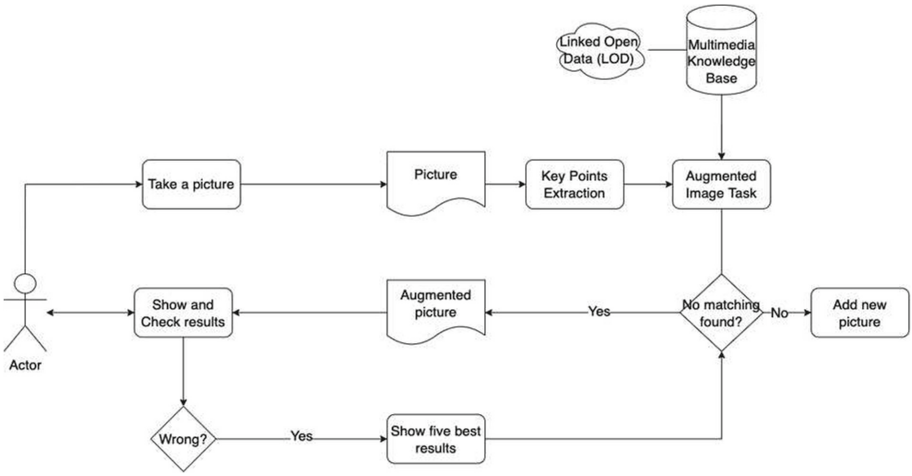


Fig. 3. Flow chart

the description from LOD, creates the augmented images, and sends it to the client (mobile device).

In detail, when a user sends an image to the server, it applies a keypoint detector that retrieves either keypoint and its description (Fig. 2). Then, the system matches the keypoint extracted from the input image and the indexed keypoint returning the LOD code id more similar to the input, namely, the one with the highest match rate. Moreover, it performs a SPARQL query to retrieve a title and description from a LOD source (i.e. DBpedia). Eventually, it creates augmented add this information to the images. We summarised such a process performed by the server in Fig. 4.

Moreover, we considered the case when our system fails, if the retrieved information is wrong or the system cannot find the match. Firstly, if the application retrieves a wrong result, the user can show the first five best results to select the correct result. If the system does not recognize anything or the proposed results are all wrong, the user can add new knowledge by adding a new picture together with the Wikipedia page link if it exists; otherwise, the picture is out to form our knowledge base.

Concerning the technologies used to develop our application, we used SOLR [41] as a retrieval system that, furthermore, indexes the local feature and the relations with the Linked Open Data. Apache Solr is an open-source search platform based on Apache Lucene that provides the methods for indexing and searching. Linked Open Data are the publisher's way of structured data that allows linking the data among them. LOD relies on standard web technologies like HTTP (Hypertext Transfer Protocol), RDF (Resource Description Framework) [6] and URI (Uniform Resource Identifier). In the retrieval process, we used the Brute Force Matcher to retrieve a code id of LOD used to perform a SPARQL [11] query to retrieve the information used then to augment the image.

In this work, we used LOD DBpedia [19], one of the most significant resources on the web. DBpedia is a Knowledge base built on several structured information found on Wikipedia. Namely, the last statistics report that the complete DBpedia data set features 38 million labels and abstracts in 125 different languages, 25.2 million links to images and 29.8 million links to external web pages; 80.9 million links to Wikipedia, and 41.2 million links to YAGO categories.

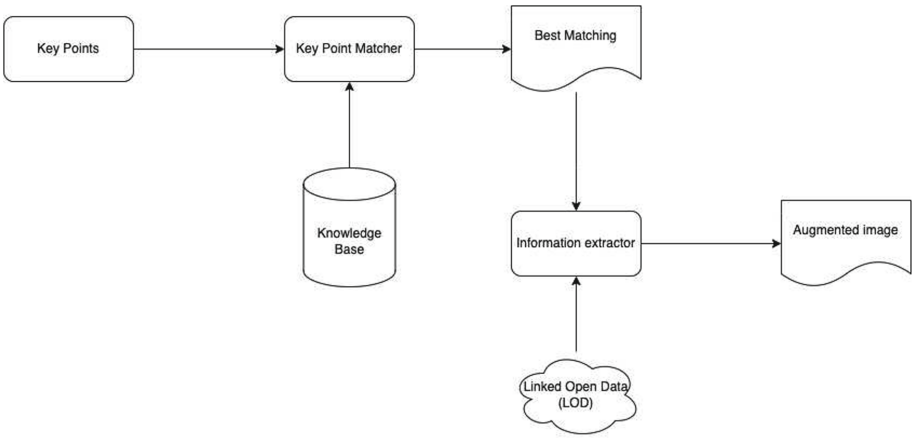


Fig. 4. Augmented image task detail

4 Use Case

In this section, we introduced a use case into the frame of the cultural heritage domain. This application has been developed to show the efficient use of the proposed framework implemented in a mobile application supported by augmented reality and the CBIR technique.

The goal, in this case, is to show the usefulness of our approach in a real scenario to support the user experience and his/her knowledge improvement. From an information retrieval point of view, the integration of LOD and CBIR is based on the mediation of the web as an important medium for publishing different kinds of cultural heritage contents, hence representing a valuable source of cultural heritage data.

We used as example the Pietà of Michelangelo Buonarotti housed in St. Peter's Basilica in Città del Vaticano. Figure 6a shows a picture taken by a user. The system processes the picture and extracts the key point with the respective descriptor, and performs matching with indexed images.

Figure 5 depicts the best matching. Then, the system queries DBpedia, retrieves the description, and overlaps it on the picture, as shown in Fig. 6b.



Fig. 5. Keypoint machining example

5 Experimental Results

This section introduces the experimental strategy and shows the results with related comments and discussion. Firstly, to choose the best keypoint Detector, we evaluated SIFT, SURF, and ORB, adding some "noises" to the images.



(a) Taken picture by user



(b) Picture with overlapped description

Fig. 6. Example

Specifically, we performed the following transformation: change of intensity and colour composition (I), noise (II), shearing (III), rotation (IV), fisheye distortion (V) and scaling (VI). In the case of rotation, we tried several angles, from 0 to 270, with step 45°, and in this work, we reported only the average results.

To evaluate the best keypoint detector we used the measure shown Eq. 1 as proposed by [23].

$$recall = \frac{\#\, correct\ matches}{\#\, correspondences} \tag{1}$$

Figure 7 summarised the result of such evaluation in terms of average matching rate. Therefore, SIFT is the best against I, II, IV and V transformations, and ORB is the best against III and VI transformations. The worst are ORB in I, II and IV transformations and SURF in V transformation.

However, accounting for the average results, SIFT is the best technique, so we choose it as a keypoint detector in our application.

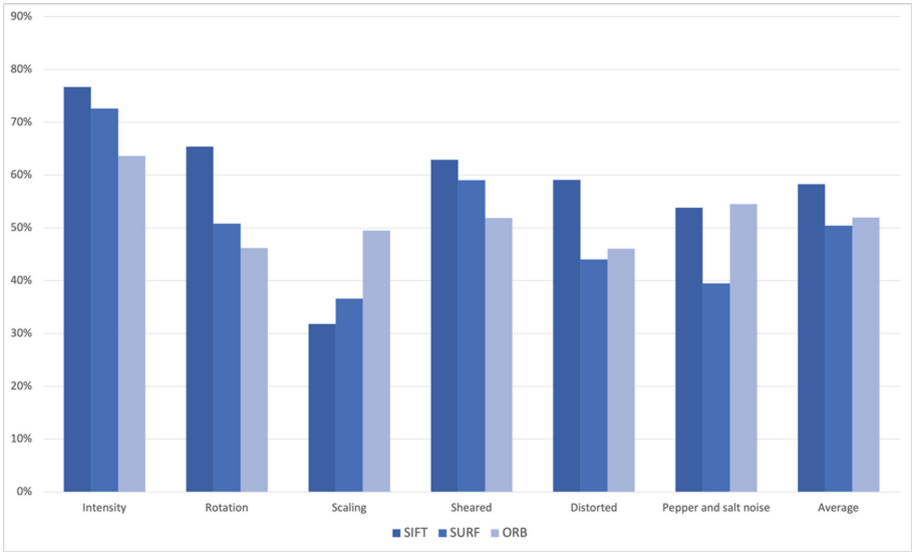


Fig. 7. Evaluation of SIFT, SURF, and ORB against intensity, scaling, rotation, sheared, fish-eye distortion, pepper and salt noise

6 Conclusion and Future Works

In this work, we proposed an application of augmented reality for the cultural heritage domain. Moreover, we developed a modular and easily extensible framework that uses local descriptors and Linked Open Data to provide a valuable and enjoyable experience for the user in the cultural heritage domain. The use of linked open data (LOD) and Semantic Web technologies, combined with the CBIR approach, has provided good results for the generation of SPARQL queries by the mobile interface.

In future work, we will improve our framework by adding new features integrating more one Linked Open Data [34] and robotic applications [21,39] to

enhance the user experience. Moreover, to improve the accuracy of our system, we will extend our work using other feature descriptors, local or global, and other ones based on deep neural networks [36]. Moreover, we want to investigate the use of domain crawler [7] to improve the knowledge of our system if we do have not enough information from LOD and the use of novel knowledge structure to represent information [33].

References

1. Affleck, J., Kalay, Y., Kvan, T.: New Heritage: New Media and Cultural Heritage. Routledge, London (2007)
2. Bay, H., Tuytelaars, T., Van Gool, L.: SURF: speeded up robust features. In: Leonardis, A., Bischof, H., Pinz, A. (eds.) ECCV 2006. LNCS, vol. 3951, pp. 404–417. Springer, Heidelberg (2006). https://doi.org/10.1007/11744023_32
3. Berners-Lee, T., Hendler, J., Lassila, O.: The semantic web. Sci. Am. **284**(5), 34–43 (2001)
4. Bres, S., Tellez, B.: Localisation and augmented reality for mobile applications in culture heritage. Computer (Long. Beach. Calif), pp. 1–5. INSA, Lyon (2006)
5. Calonder, M., Lepetit, V., Strecha, C., Fua, P.: BRIEF: binary robust independent elementary features. In: Daniilidis, K., Maragos, P., Paragios, N. (eds.) ECCV 2010. LNCS, vol. 6314, pp. 778–792. Springer, Heidelberg (2010). https://doi.org/10.1007/978-3-642-15561-1_56
6. Candan, K.S., Liu, H., Suvarna, R.: Resource description framework: metadata and its applications. ACM SIGKDD Explor. Newsl. **3**(1), 6–19 (2001)
7. Capuano, A., Rinaldi, A.M., Russo, C.: An ontology-driven multimedia focused crawler based on linked open data and deep learning techniques. Multimed. Tools Appl. **79**(11), 7577–7598 (2020). https://doi.org/10.1007/s11042-019-08252-2
8. Clini, P., Frontoni, E., Quattrini, R., Pierdicca, R.: Augmented reality experience: from high-resolution acquisition to real time augmented contents. Adv. MultiMedia **2014** (2014). https://doi.org/10.1155/2014/597476
9. Cranmer, E., Jung, T.: Augmented reality (AR): business models in urban cultural heritage tourist destinations. In: APacCHRIE Conference, pp. 21–24 (2014)
10. Dastageeri, H., Storz, M., Koukofikis, A., Knauth, S., Coors, V.: Approach and evaluation of a mobile video-based and location-based augmented reality platform for information brokerage. In: ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XLII-4/W1, pp. 151–157, September 2016. https://doi.org/10.5194/isprs-archives-XLII-4-W1-151-2016
11. Valle, E.D., Ceri, S.: Querying the semantic web: SPARQL. In: Domingue, J., Fensel, D., Hendler, J.A. (eds.) Handbook of Semantic Web Technologies. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-540-92913-0_8
12. Fritz, F., Susperregui, A., Linaza, M.T.: Enhancing cultural tourism experiences with augmented reality technologies. In: The 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2005)
13. Ghouaiel, N., Garbaya, S., Cieutat, J.M., Jessel, J.P.: Mobile augmented reality in museums: towards enhancing visitor's learning experience. Int. J. Virtual Reality **17**(1), 21–31 (2017)
14. Han, D., Leue, C., Jung, T.: A tourist experience model for augmented reality applications in the urban heritage context. In: APacCHRIE Conference, pp. 21–24 (2014)

15. Han, D.-I.D., Weber, J., Bastiaansen, M., Mitas, O., Lub, X.: Virtual and augmented reality technologies to enhance the visitor experience in cultural tourism. In: tom Dieck, M.C., Jung, T. (eds.) Augmented Reality and Virtual Reality. PI, pp. 113–128. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-06246-0_9
16. Han, J.G., Park, K.W., Ban, K.J., Kim, E.K.: Cultural heritage sites visualization system based on outdoor augmented reality. AASRI Procedia **4**, 64–71 (2013). https://doi.org/10.1016/j.aasri.2013.10.011. https://www.sciencedirect.com/science/article/pii/S2212671613000127. 2013 AASRI Conference on Intelligent Systems and Control
17. Jing, C., Junwei, G., Yongtian, W.: Mobile augmented reality system for personal museum tour guide applications. In: IET International Communication Conference on Wireless Mobile and Computing (CCWMC 2011), pp. 262–265 (2011). https://doi.org/10.1049/cp.2011.0887
18. Candan, K.S., Sapino, M.L.: Data Management for Multimedia Retrieval. Cambridge University Press, Cambridge (2010)
19. Lehmann, J., et al.: DBpedia-a large-scale, multilingual knowledge base extracted from Wikipedia. Semant. Web **6**(2), 167–195 (2015)
20. Lowe, D.G.: Object recognition from local scale-invariant features. In: Proceedings of the Seventh IEEE International Conference on Computer Vision, vol. 2, pp. 1150–1157. IEEE (1999)
21. Madani, K., Rinaldi, A.M., Russo, C.: Combining linked open data and multimedia knowledge base for digital cultural heritage robotic applications. In: 2021 IEEE International Symposium on Multimedia (ISM), pp. 196–203. IEEE (2021)
22. Makantasis, K., Doulamis, A., Doulamis, N., Ioannides, M., Matsatsinis, N.: Content-based filtering for fast 3D reconstruction from unstructured web-based image data. In: Ioannides, M., Magnenat-Thalmann, N., Fink, E., Žarnić, R., Yen, A.-Y., Quak, E. (eds.) EuroMed 2014. LNCS, vol. 8740, pp. 91–101. Springer, Cham (2014). https://doi.org/10.1007/978-3-319-13695-0_9
23. Mikolajczyk, K., Schmid, C.: A performance evaluation of local descriptors. IEEE Trans. Pattern Anal. Mach. Intell. **27**(10), 1615–1630 (2005)
24. Moscato, V., Picariello, A., Rinaldi, A.M.: A recommendation strategy based on user behavior in digital ecosystems. In: Proceedings of the International Conference on Management of Emergent Digital EcoSystems, pp. 25–32 (2010)
25. Muscetti, M., Rinaldi, A.M., Russo, C., Tommasino, C.: Multimedia ontology population through semantic analysis and hierarchical deep features extraction techniques. Knowl. Inf. Syst. **64**, 1283–1303 (2022). https://doi.org/10.1007/s10115-022-01669-6
26. Neuhofer, B., Buhalis, D., Ladkin, A.: A typology of technology-enhanced tourism experiences. Int. J. Tour. Res. **16**(4), 340–350 (2014)
27. Olojede, A.: Investigating image processing algorithms for provision of information in rock art sites using mobile devices. Master's thesis, University of Cape Town (2016)
28. Purificato, E., Rinaldi, A.M.: Multimedia and geographic data integration for cultural heritage information retrieval. Multimed. Tools Appl. **77**(20), 27447–27469 (2018). https://doi.org/10.1007/s11042-018-5931-7
29. Purificato, E., Rinaldi, A.M.: A multimodal approach for cultural heritage information retrieval. In: Gervasi, O., et al. (eds.) ICCSA 2018. LNCS, vol. 10960, pp. 214–230. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-95162-1_15
30. Rigby, J., Smith, S.P.: Augmented reality challenges for cultural heritage. Applied Informatics Research Group, University of Newcastle, Newcastle (2013)

31. Rinaldi, A.M., Russo, C.: A semantic-based model to represent multimedia big data. In: Proceedings of the 10th International Conference on Management of Digital EcoSystems, pp. 31–38. ACM (2018)
32. Rinaldi, A.M., Russo, C.: User-centered information retrieval using semantic multimedia big data. In: 2018 IEEE International Conference on Big Data (Big Data), pp. 2304–2313. IEEE (2018)
33. Rinaldi, A.M., Russo, C.: Using a multimedia semantic graph for web document visualization and summarization. Multimed. Tools Appl. **80**(3), 3885–3925 (2020). https://doi.org/10.1007/s11042-020-09761-1
34. Rinaldi, A.M., Russo, C., Madani, K.: A semantic matching strategy for very large knowledge bases integration. Int. J. Inf. Technol. Web Eng. (IJITWE) **15**(2), 1–29 (2020)
35. Rinaldi, A.M., Russo, C., Tommasino, C.: A semantic approach for document classification using deep neural networks and multimedia knowledge graph. Expert Syst. Appl. **169**, 114320 (2021)
36. Rinaldi, A.M., Russo, C., Tommasino, C.: A knowledge-driven multimedia retrieval system based on semantics and deep features. Future Internet **12**(11), 183 (2020)
37. Rodrigues, J.M.F., et al.: Mobile augmented reality framework - MIRAR. In: Antona, M., Stephanidis, C. (eds.) UAHCI 2018. LNCS, vol. 10908, pp. 102–121. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-92052-8_9
38. Rublee, E., Rabaud, V., Konolige, K., Bradski, G.: ORB: an efficient alternative to SIFT or SURF. In: 2011 International Conference on Computer Vision, pp. 2564–2571. IEEE (2011)
39. Russo, C., Madani, K., Rinaldi, A.M.: An unsupervised approach for knowledge construction applied to personal robots. IEEE Trans. Cogn. Dev. Syst. **13**(1), 6–15 (2020)
40. Russo, C., Madani, K., Rinaldi, A.M.: Knowledge construction through semantic interpretation of visual information. In: Rojas, I., Joya, G., Catala, A. (eds.) IWANN 2019. LNCS, vol. 11507, pp. 246–257. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-20518-8_21
41. Shahi, D.: Apache Solr: An Introduction. In: Apache solr, pp. 1–9. Springer, Berkeley (2015). https://doi.org/10.1007/978-1-4842-1070-3_1
42. Shin, C., Hong, S.H., Yoon, H.: Enriching natural monument with user-generated mobile augmented reality mashup. J. Multimed. Inf. Syst. **7**(1), 25–32 (2020)
43. Tam, D.C.C., Fiala, M.: A real time augmented reality system using GPU acceleration. In: 2012 Ninth Conference on Computer and Robot Vision, pp. 101–108 (2012). https://doi.org/10.1109/CRV.2012.21
44. Titchen, S.M., et al.: On the construction of outstanding universal value: UNESCO's world heritage convention (convention concerning the protection of the world cultural and natural heritage, 1972) and the identification and assessment of cultural places for inclusion in the world heritage list (1995)
45. tom Dieck, M.C., Jung, T.H.: Value of augmented reality at cultural heritage sites: a stakeholder approach. J. Destination Mark. Manag. **6**(2), 110–117 (2017). https://doi.org/10.1016/j.jdmm.2017.03.002. https://www.sciencedirect.com/science/article/pii/S2212571X16300774. Special edition on Digital Destinations
46. Ufkes, A., Fiala, M.: A markerless augmented reality system for mobile devices. In: 2013 International Conference on Computer and Robot Vision, pp. 226–233 (2013). https://doi.org/10.1109/CRV.2013.51
47. Vargo, S.L., Lusch, R.F.: From goods to service(s): divergences and convergences of logics. Ind. Mark. Manage. **37**(3), 254–259 (2008)

48. Vi, S., da Silva, T.S., Maurer, F.: User experience guidelines for designing HMD extended reality applications. In: Lamas, D., Loizides, F., Nacke, L., Petrie, H., Winckler, M., Zaphiris, P. (eds.) INTERACT 2019. LNCS, vol. 11749, pp. 319–341. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-29390-1_18
49. Yovcheva, Z., Buhalis, D., Gatzidis, C.: Engineering augmented tourism experiences. In: Cantoni, L., Xiang, Z.P. (eds.) Information and Communication Technologies in Tourism 2013, pp. 24–35. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-36309-2_3
50. Yu, L.: Linked open data. In: Yu, L. (ed.) A Developer's Guide to the Semantic Web, pp. 409–466. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-15970-1_11