An Intelligent Machine-Driven Perspective to Archaeological Pottery Reassembly

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Wilson Sakpere
https://orcid.org/0000-0003-2429-8924
University of Bologna, Italy

Valentina Gallerani
University of Bologna, Italy

INTRODUCTION

Information is an imperative concept that humans use to communicate because communicating aids understanding. Within an information, there could be other components of data such as images, video, numbers and text. The need to stay informed in modern day has resulted in various ways of transmitting information with the use of technologies such as the computer and internet. Hence, Information and Communication Technologies (ICT) has played an important role in this aspect. ICT is the use of modern equipment and methods to transmit and exchange information. ICT has helped in understanding the human society and way of life. The applications of ICT include research and development in a variety of application fields such as teaching, transport, business, entertainment, politics, agriculture, medicine and various industry and academic disciplines among others. One of such disciplines, that this article is based on, is archaeology.

Archaeology is a discipline that recovers, studies and analyses ancient and modern artefacts and material remains from past societies of humans and closely related species, recording its primary data for the purpose of reusing them for historical understanding of human culture (Jeffrey, 2010:47). Archaeologists have used ICT as a means of making, keeping and preserving records and information to make it available for further research and future use (Eiteljorg, 2004; Marchetti *et al.*, 2017; A. Smith, 2004). This is to considerably reduce the likelihood of information degradation and loss (A. Smith, 2004). Hence, various methods have been used by social scientists and digital humanists to preserve historical artefacts and relics such as literary texts and arts, frescoes and potsherds (Sabharwal, 2015:60-61).

In particular, archaeologists have employed different time-consuming means of studying and preserving historical relics (Marchetti *et al.*, 2017). Such methods include physical examination, classification, illustration and reconstruction of potsherds through drawing. These methods are carried out manually, making the archaeologist spend time and effort to observe and possibly extrapolate from the observations (Drucker, 2012:89). However, reconstruction of many excavated fragments of potsherds is still a major concern. This paper proposes a path towards an optimal means to reconstruct excavated archaeological potsherds to a high standard. To achieve this, image analysis techniques (computer vision) as well as machine learning algorithms are considered.

In addition, the terms ‘reconstruct’ and ‘reassemble’ are used interchangeably in this paper to mean the same thing. The remainder of this paper is structured as follows: Section 2 reviews some related works from a general point of view and highlights the potentials inherent in computer vision and ma-

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chine learning; Section 3 delves into the research problem, identifying the research questions, methods, objectives and methodology that this study is based on; Section 4 concludes our discussion.

BACKGROUND

As archaeologists study the historic and prehistoric human activities through reconstructing discovered ancient artefacts to have a grounded understanding of the prehistoric culture, the ability to carry out these reconstructions accurately and within reasonable time become pertinent. In this technology era of virtual and augmented reality, among others, researchers have been applying the use of digital technologies to make work faster and output optimal. This has helped in making professional life easier, more enjoyable and more productive, leading to what is now known as 'smart environment'. Therefore, applying technological means to solve critical issues in the archaeological field is desirable.

Hence, many studies have attempted to solve the reconstruction problem. For example, the study of Kampel and Sablatnig (2003) developed a system that can process both complete and broken vessels. This was achieved using two reconstruction strategies known as: "shape from silhouette based method for complete vessels and a profile based method for fragments" (Kampel & Sablatnig, 2003). While using these strategies have improved performance with an acceptable accuracy, it is nonetheless dependent on certain conditions being met, thus requiring further investigations that will improve accuracy.

Likewise, Smith, Bespalov, Shokoufandeh and Jeppson (2010) investigated methods of classification and reconstruction of images of excavated archaeological ceramic fragments based on their colour and texture information. This was achieved by using Scale Invariant Feature Transform (SIFT) and a feature descriptor based on Total Variation Geometry (TVG) (P. Smith *et al.*, 2010). However, the performance of these descriptors was not satisfactory in terms of effectiveness and accuracy. Also, the study of Puglisi, Stanco, Barone and Mazzoleni (2015) proposed a system that uses SIFT as well. The system uses image processing techniques to automatically identify and analyse images of the structural components of potsherds through "optical microscopy". As a result, the suitable features can then be computed and analysed for classification purposes. In addition, this system aims at segmenting the acquired images and extracting their features for pottery classification. To achieve this and for the sake of better accuracy, the authors chose to use SIFT feature point method, where the feature points are extracted and matched with related pairs. While this system improves on the ones before it, it falls short in providing an optimal solution with a high accuracy, hence opening the path to further studies (Puglisi *et al.*, 2015).

Furthermore, Makridis and Daras (2012) focused on a technique for accurate and automatic classification of potsherds. The technique was implemented in four steps namely: feature extraction, feature fusion, feature selection and classification. This approach attempted to reduce the computational complexity problem with a "bag of words (BoW)" method that uses the features extracted from the images to create a "global descriptor" vector for the images (Makridis & Daras, 2012). However, while this technique turned out to be quite efficient, how and if this solution reduces computational complexity is still an open issue.

Finally, Roman-Rangel, Jimenez-Badillo and Marchand-Maillet (2016) proposed Histogram of Spherical Orientations (HoSO), a method for automatic analysis of potsherds by applying computer vision techniques. This method analyses the external frontal view of the potsherd alone, processes 3D data by using only the points coordinates without using colour, texture or faces, and efficiently encodes the information from the points coordinates. They posit that the advantages include substantial time reduc-