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Research Paper

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Machine Learning Method for Knee Osteoarthritis Detection from Magnetic Resonance Imaging: A 3-D Independent Component Analysis-Based Approach

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***Abstract*—**Osteoarthritis (OA) is a global disease that still does not have a treatment for its process and that impacts people's quality of life. Nowadays, medical images such as magnetic resonance (MR) images are widely used for the OA diagnosis. For this, a medical specialist analyzes medical images by measuring the changes and in particular for knee OA, the changes in the compartment of the tibio-femoral cartilage. In this work, we describe a novel knee OA diagnostic method, which use a Support Vector Machine (SVM) algorithm and is capable of detecting the disease from MR images. Our proposed approach is based on the application of the Independent Component Analysis (ICA) technique to 3-D information from MR images of a real cohort. The experimental results showed that our ICA-SVM machine learning model achieved 86% of testing accuracy with both 72% of specificity and 100% of sensitivity, once trained with a small MR image dataset.

***Keywords*—** Osteoarthritis, Magnetic Resonance Imaging, Independent Component Analysis, Support Vector Machine.

I. INTRODUCTION

Osteoarthritis (OA) is a joint disorder caused by aging and wear and tear in a joint. The pathology of OA is uncertain and there is still no effective intervention against the disease process. Worldwide, this disease affects 500 million people (source: Osteoarthritis Foundation International) and is one of the main health problems due to its high prevalence. Therefore, the OA is considered as the most common cause of permanent disability in people over 65 years of age and occurring more frequently in the knees, hip, and hands. On the other hand, this disease presents a significant cost to the health systems and economy of a country. This is due to costs such as visits, medicines and medical treatments, alteration in labor productivity, quality of life and social costs.

From the scientific point of view, an early diagnosis is crucial for the treatment of the disease. For this, medical images such as X-rays, ultrasounds, and magnetic resonance (MR) images are widely used to visualize what is happening under an arthritic surface. In particular, radiography is the standard used for the preliminary detection of OA due to its low cost; however, ultrasound and MR images provide results that are more informational.

In the diagnosis of the disease, the standard for evaluating the severity of knee OA in radiographs is the Kellgren-Lawrence (KL) scale [1]. This standard is also used in the evaluation of hip OA, and MR image evaluation because there is a correlation between the KL scale and other OA evaluation scales in MR images [2][3]. In particular, the KL scale classifies the severity of OA in five grades ranging from zero to four: 'normal' (KL0), 'doubtful' (KL1), 'minimal' (KL2), 'moderate' (KL3), and 'severe' (KL4), respectively.

In this work, a machine learning-based knee OA detection system from MR images is proposed. This system is capable of detecting the presence of OA considering two classification categories: 'non-OA' and 'OA'. The main contribution of the proposed method is the complementary use of Independent Component Analysis (ICA) applied to 3-D data obtained from MR images and a Support Vector Machine (SVM) classifier algorithm by supervised learning.

This work is organized into five sections. Section II contains related works on detection of OA from 3-D information. In Section III, we introduce the procedures for implementation of proposed system. Section IV covers the computational experimentation and results obtained. Finally, in Section V provides research conclusions with some possible directions for future research.

II. RELATED WORK

A review of the literature on knee OA detection methods using both machine learning and deep learning techniques was carried out. This review also considers a focus on the MR image databases used and artificial intelligence (AI) techniques based on analysis.

Machine learning has been widely used to detect and grade knee OA. Du et al. [4] built a prediction model from MR images and used Principal Component Analysis (PCA) to predict the KL grade by using four machine learning methods: Artificial Neural Network (ANN), SVM, Random Forest (RF), and Naïve Bayes (NB); the best performance was achieved by ANN with an area under the curve (AUC) value of 76.10% and F-score of 71.40%. Moustakidis et al. [5] proposed a machine learning approach to recognize MR images with symptomatic OA or being at high risk of developing OA based on machine learning algorithms such as Linear Discriminant Analysis (LDA), Decision Tree (DT), K-Nearest Neighbors (KNN), SVM, AdaBoost, RF, Deep Neural Network (DNN), and fuzzy based algorithms; with classification accuracies up to 86.95% with DNN algorithm.

On the other hand, deep learning methods such as Convolutional Neural Networks (CNNs) have achieved state-of-the-art performance on many image classification tasks in recent times [6]. Ambellan et al. [7] proposed a method for the automated segmentation of knee bones and cartilage from MR images by using 3-D Statistical Shape Models (SSMs) as well as 2-D and 3-D CNNs. Chang et al. [8] built a Convolutional Siamese Network (CSN) to assess knee pain with an AUC value of 0.808 from MR imaging scans through Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain scores. Guida et al. [9] proposed a 3D-CNN model to recognize with an accuracy of 83.00% OA from MR images and predict KL grade of severity with an accuracy of 54.00%.
In summary, this literature review proposed different AI approaches for the detection of knee OA from MR images. Some techniques identified based on analysis were PCA, LDA, SVM and CNN, but the use of ICA techniques was not detected. Furthermore, in most of the reviewed works, MR images were obtained from Osteoarthritis Initiative (OAI). This database was initiated to promote the evaluation of OA biomarkers as potential surrogate endpoints [10]. The use of this repository is scientifically relevant as it provides data from the cohort study, documenting the image, biochemical, genetic and risk markers of knee OA.

III. MATERIALS AND METHOD

A. *Proposed Architecture*
The proposed method consists mainly of both a data processing module and binary classification module, which process the 3-D data from MR images as shown in Figure 1.

In the first module, region of interest (ROI) extraction is apply to an input MR image to reduce both the complexity in the classification task and computational cost. In particular, the selection of the ROI is according to the KL scale criteria where just the tibio-femoral cartilage compartment is crucial in the evaluation. Then, the resulting ROI is analyzed by ICA method for both feature extraction and data reduction. The resulting 3-D data contain ICA components, which stand for features information and patterns of the input MR image.

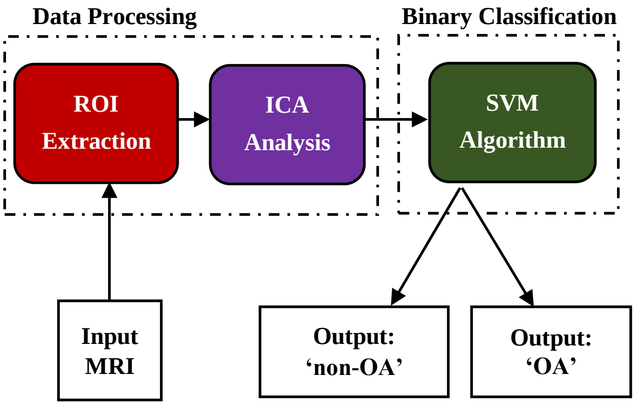

Figure 1. Overview of the proposed OA detection architecture.

In the second module, the obtained ICA data is used as input to a previously trained machine learning algorithm for binary classification. To this end, ICA data is converted to 2-D data to enable its use with state-of-the-art machine learning algorithm. In our approach, SVM algorithm is employ for detecting the OA in the input MR image. In our approach, we considered two classification categories according to the KL scale: 'non-OA' (KL≤1) and 'OA' (KL≥2).

B. *Experimental Data*
The MR images used in this work were obtained from the OAI database. In particular, the KXR SQ-01 clinical study was used, which contains medical images of the coronal and sagittal planes of the left and right knees, obtained from 4,396 patients of different ages, ethnicities and races. The acquisition of MR images of the study was performed using a Siemens Magnetom Trio scanner, which contains a 3-Tesla magnet, and then processed with Syngo MR 2003T software, resulting in DICOM (Digital Imaging and Communications in Medicine) file format. Furthermore, this clinical study contains the medical diagnosis on the KL scale and others.

C. *Data Processing*
For experimentation, 400 DICOM series containing MR images of the 2-D sagittal plane of the patient's right knee were manually selected. In the selection, 200 data classified as 'non-OA' and 200 data classified as 'OA' were considered, according to the following distribution: KL0-100, KL1-100, KL2-66, KL3-68, and KL4-66.

DICOM data also contains metadata with patient information. Because of this, the data were converted to the NRRD (Nearly Raw Raster Data) format so that only the contained MR images could be used. On the other hand, each MR image contains 189 frames (384x384 pixels) with various scan sequences of the patient's entire knee. As we only considered one scan per patient, both the first 26 frames and ROI extraction of each MR image were selected automatically using a Python code. The ROI corresponds to the area (180x180 pixels) near the tibio-femoral compartment of the patient. In Figure 2, it is possible to see both the 26 selected frames as an arrangement of 2-D images and the 3-D projection.

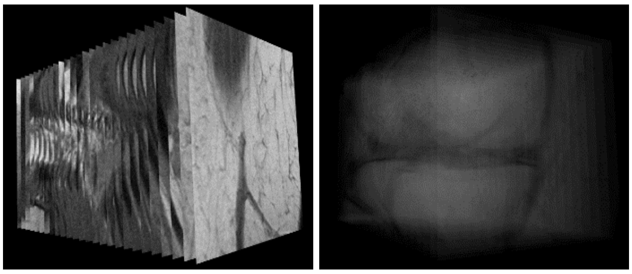

Figure 2. 2-D array of processed ROI of a MR image (right). 3-D projection of the ROI data (left).

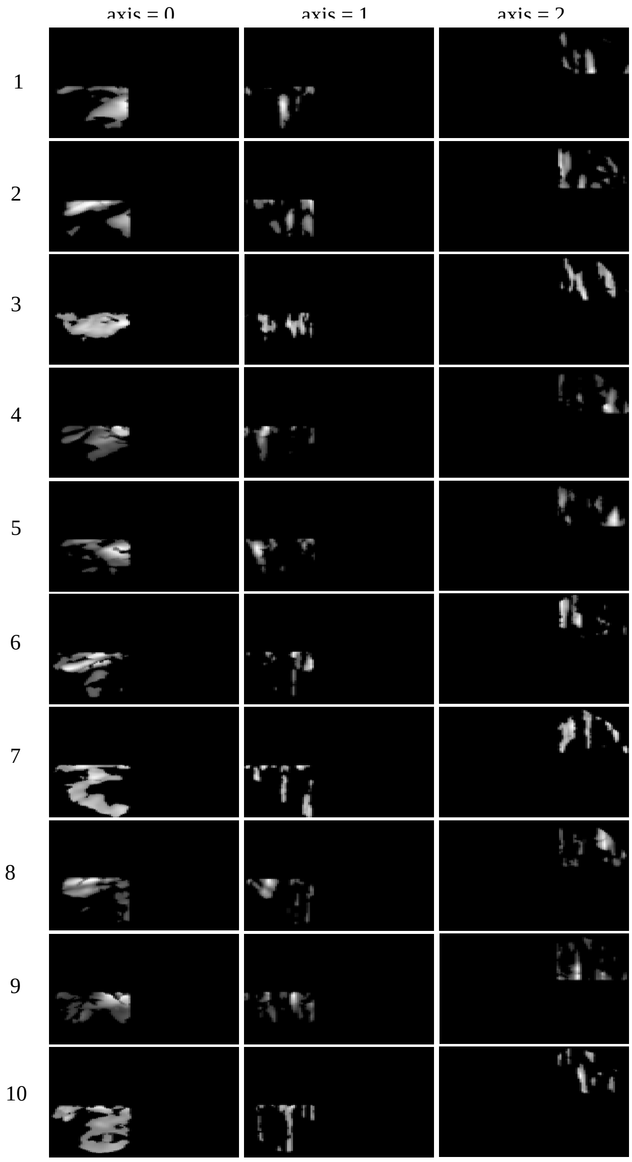

Figure 3. Plot of the 10- masked ICA components obtained from the training subset.

Table 1. Details of the subsets used in supervised learning.

Subset	Images	KL 0	KL 1	KL 2	KL 3	KL 4
Training	200	50	50	33	34	33
Testing	200	50	50	33	34	33

Furthermore, for the development of machine learning model the dataset was split into two subsets for the use in training and testing, as described in Table 1.

In our approach, we apply ICA analysis to the 3-D information from each subset for patterns with independent sources. For this, each subset of Table 1 represents a 4-D image as a Python array of the shape [200, 180, 180, 26]. Thus, a canonical ICA was performed using the CanICA algorithm provided by Nilearn, originally designed for neuroimaging processing, to obtain components with features from an MR image mask. In this process, first the MR images of each subset are stored in a NIfTI (Neuroimaging Informatics Technology Initiative) file for computational processing. Then, the decomposition is performed by extracting the gray matter part of the image, according to the CanICA algorithm strategy, to obtain 10-masked ICA components. The result of this process is a 4-D image with the extracted ICA components represented as a Python array of the shape [200, 180, 180, 10] for each subset. In Figure 3, the 10-masked ICA components are shown.

*D. **Binary Classification***

In our approach a C-Support Vector Classification (SVC) machine learning algorithm, provided by scikit-learn library is proposed to recognize between ‘non-OA’ and ‘OA’ from ICA components extracted from MR images. The implementation of the machine learning model as well as the processing of the all MR images was carried out in Google Colaboratory by using the Python programming language.

$$k(X,Y) = (\gamma X^T Y)^4 \quad (1)$$

During the training stage of our model, SVC hyperparameters were defined by using GridSearchCV algorithm provided by scikit-learn library. Therefore, the defined regularization value was 0.01 with a homogeneous polynomial kernel function as denoted in (1), where X and Y are the input vectors, and γ is the slope that defines how far the influence of an input data reaches. For validation of the model, a stratified 10-fold cross-validation considering 20.00% of the training subset was used.

IV. RESULTS AND DISCUSSION

For performance evaluation of our ICA-SVM algorithm, the testing subset was used for the binary classification task. Therefore, Table 2 shows the resulting scores obtained from the training and testing stages, considering some standard statistic metrics such as accuracy (acc.), standard deviation (S.D.), precision (prec.), recall, and F-score.

Table 2. Resulting evaluation metrics of the machine learning model considering validation and testing.

Validation		**Testing**			
Acc. [%]	S.D. [%]	Acc. [%]	Prec. [%]	Recall [%]	Fscore [%]
85.25	3.61	86.00	78.12	100.00	87.72

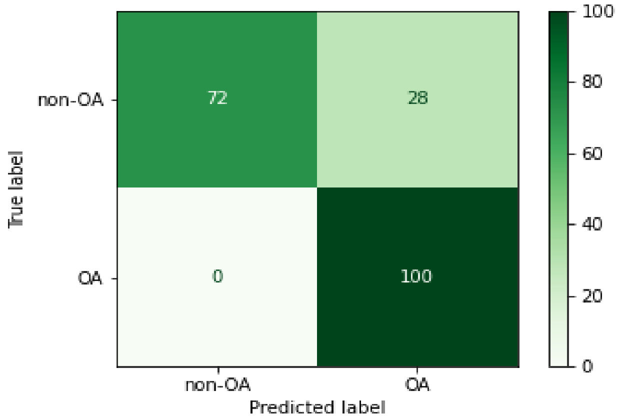

Figure 4. Confusion matrix resulting from ICA-SVM method.

Figure 4 details the resulting predictions of our model once tested with testing subset. As we can see from Table 2 and Figure 4, our kernelized model demonstrated its ability to linearly separate data from a complex dataset from a 4-degree long polynomial kernel. In this way, promising results were achieved as it is possible to see that 100.00% of sensitivity was reached with 28.00% false positive instances and the specificity reached by our machine learning model was 72.00%.

These experimental results demonstrate the capability of our proposed method to achieve an acceptable performance in the knee OA detection from MR images. Furthermore, taking into account the literature review carried out our ICA-SVM method outperformed both Du et al. and Guida et al. in F-score and accuracy respectively, and failed to narrowly outperform Moustakidis et al. in accuracy achieved (86.00% vs. 86.95%).

V. Conclusion

In this work, we introduced a machine learning approach to diagnose MR images according to the binary classification: 'non-OA' and 'OA'. In this way, we demonstrate that using canonical ICA analysis applied to 3-D data it is possible to recognize between MR images with different pathologies and classify them. In particular, the proposed approach is also interesting due to the nature of the ICA algorithm used, which was designed for neuroimaging analysis.

Although the dataset used was not large, through supervised learning the proposed machine learning model reaches acceptable prediction rates. In our approach, we proved that a SVM algorithm with a homogeneous polynomial kernel is able to learn from both complex medical images and small dataset. In future works, we will study the complementary use of ICA components from MR images and a CNN to try to achieve better predictive rates in supervised learning.

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