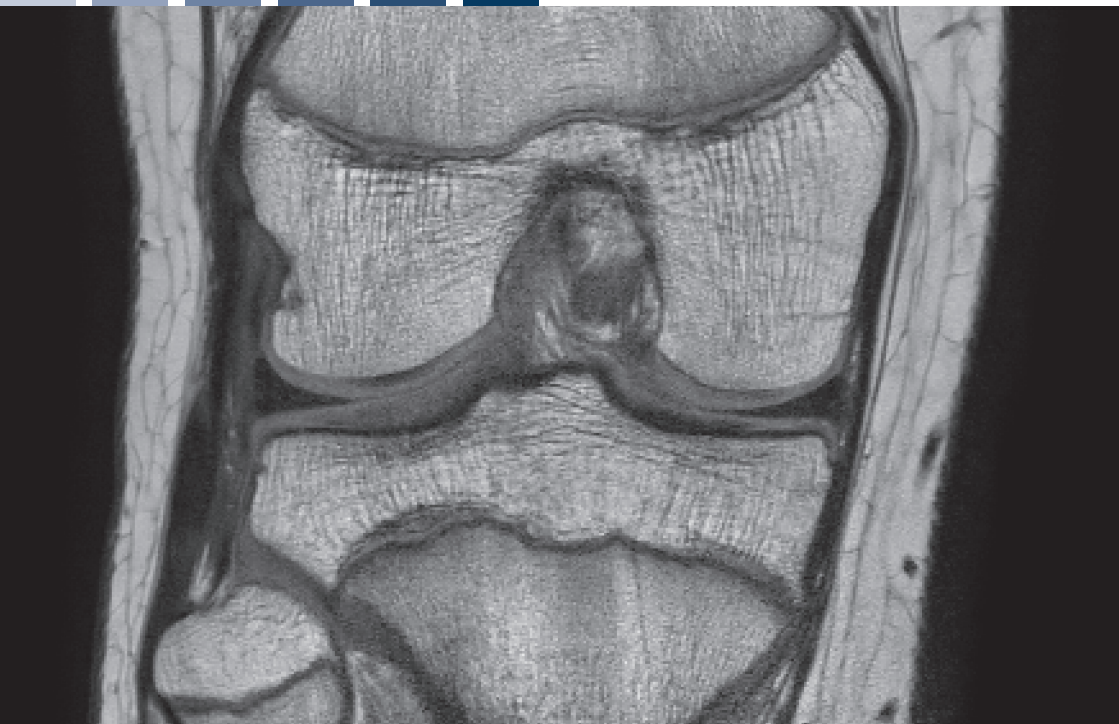
Towards Automated Age Estimation of Young Individuals

A New Computer-Based Approach Using 3D Knee MRI

Markus Auf der Mauer



Towards Automated Age Estimation of Young Individuals: A New Computer-Based Approach Using 3D Knee MRI

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> There are no secrets to success. It is the result of preparation, hard work, and learning from failure.
>
> Colin Powell

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Abstract

Background: Age estimation from medical images plays an important role in forensic medicine to determine the chronological age of individuals lacking legal documentation or to discriminate minors from adults. Current methods for imaging-based age estimation are labour-intensive, subjective, and involve radiation exposure. Recent studies indicate that magnetic resonance imaging (MRI) offers a viable alternative to established methods. The *goal of this work* is to develop a fully automated, computer-based, and non-invasive method to estimate the chronological age of male adolescents and young adults based on knee MRIs.

Materials and Methods: A total of 489 three-dimensional knee MRIs were acquired from 299 male Caucasian subjects aged 13 to 21 years. The dataset was expanded with numeric data of the subjects (anthropometric measurements and assessments of knee bone maturation). The proposed solution for automated age estimation is composed of three parts: (a) *pre-processing* to standardize the data, (b) *bone segmentation* via convolutional neural networks (CNNs) to extract age-relevant structures from the images, and (c) *age estimation*. Three different methods were investigated in part (c). *Method 1* (M1) is based on machine learning (ML) and uses the numeric data to solve the task. *Method 2* (M2) is composed of a CNN which takes in knee MRIs and outputs age predictions per image slice. Subsequently, an ML algorithm is trained on these predictions and on the numeric data to estimate a single and final age per subject. Finally, *Method 3* (M3) is a variant of M2 which incorporates the numeric data into the CNN trained on knee MRIs. Similar to M2, M3 predicts a final age per subject based on ML but using only the age predictions of the CNN.

Results: The best performing method is M2 and achieves a mean absolute error in age regression of 0.69 ± 0.47 years and an accuracy in majority classification of 90.93% using the 18-year-threshold.

Conclusions: The results demonstrate the potential of this approach for age estimation based on knee MRI and ML-techniques and is expected to improve further with the incorporation of additional datasets.

Keywords: Automated age estimation · MRI · Knee · Machine learning · Convolutional neural networks · Segmentation

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List of Abbreviations

Abbrv.		Meaning
3D	=	Three-Dimensional
AE	=	Absolute Error
AGFAD	=	international and interdisciplinary study Group on Forensic Age Diagnostics of the German Society of Legal Medicine
AI	=	Artificial Intelligence
AM	=	Anthropometric Measurements
ANN	=	Artificial Neural Network
AUC	=	Area Under the Curve
BAMF	=	Bundesamt für Migration und Flüchtlinge
BFC	=	Bias Field Correction
BL	=	Baseline
BN	=	Batch Normalization
CCW	=	Counter-Clockwise
CNN	=	Convolutional Neural Network
COG	=	Center of Gravity
CPU	=	Central Processing Unit
CT	=	Computed Tomography
CV	=	Cross-Validation
CW	=	Clockwise
DCNN	=	Deep Convolutional Neural Network
DF	=	Distal Femur
DICOM	=	Digital Imaging and Communications in Medicine
DO	=	Dropout
DSC	=	Dice Similarity Coefficient
DTC	=	Decision Tree Classifier
EASO	=	European Asylum Support Office
ELU	=	Exponential Linear Unit
ETC	=	Extremely Randomized Trees Classifier
ETR	=	Extremely Randomized Trees Regressor
EU	=	European Union

Abbrv.		Meaning
FC	=	Fully-Connected
FN	=	False Negative
FNR	=	False Negative Rate
FOV	=	Field of View
FP	=	False Positive
FPR	=	False Positive Rate
FU	=	Follow-UP
GAP	=	Global Average Pooling
GBC	=	Gradient Tree Boosting Classifier
GBR	=	Gradient Tree Boosting Regressor
GIGO	=	Garbage In, Garbage Out
GMP	=	Global Max Pooling
GNB	=	Gaussian Naive Bayes
GP	=	Greulich and Pyle
GUI	=	Graphical User Interface
ID	=	Identification
IQR	=	Interquartile Range
IoU	=	Intersection-over-Union
ITK	=	Insight Segmentation and Registration Toolkit
KJC	=	Knee Joint Cavity
KNC	=	K-Nearest-Neighbors Classifier
KNN	=	K-Nearest-Neighbors
LLL	=	Lower Leg Length
LOOCV	=	Leave-One-Out Cross-Validation
LR	=	Linear Regression
LReLU	=	Leaky Rectified Linear Unit
MAE	=	Mean Absolute Error
MFS	=	Magnetic Field Strength
ML	=	Machine Learning
MLP	=	Multilayer Perceptron
MRI	=	Magnetic Resonance Imaging
MSE	=	Mean Squared Error
N3	=	Nonparametric nonuniform intensity normalization algorithm
N4ITK	=	Improved N3 algorithm for ITK

Abbrv.		Meaning
NCC	=	Normalized Cross-Correlation
OC	=	Ossification Classes
PCA	=	Principal Component Analysis
PCL	=	Posterior Cruciate Ligament
PF	=	Proximal Fibula
PReLU	=	Parametric Rectified Linear Unit
PT	=	Proximal Tibia
ReLU	=	Rectified Linear Unit
RF	=	Random Forests
RFC	=	Random Forests Classifier
RFR	=	Random Forests Regression
RMSE	=	Root Mean Squared Error
ROC	=	Receiver Operating Characteristic
ROI	=	Region of Interest
SENSE	=	SENSitivity Encoding
SGD	=	Stochastic Gradient Descent
SKJ	=	Score of the Knee Joint
SVC	=	Support-Vector Classification
SVM	=	Support-Vector Machine
SVR	=	Support-Vector Regression
TE	=	Echo Time
TN	=	True Negative
TNR	=	True Negative Rate
TP	=	True Positive
TPR	=	True Positive Rate
TR	=	Repetition Time
TSE	=	Turbo Spin Echo
TW2	=	Tanner-Whitehouse method 2
UKE	=	University Medical Center Hamburg-Eppendorf
VOI	=	Volume of Interest
VTK	=	Visualization Toolkit