Estimation of Bone Mineral Density Using Machine Learning Approach

Bharti Joshi[1], Shivangi Agarwal[2(✉)], Leena Ragha[1], and Navdeep Yadav[3]

[1] Department of Computer Engineering, Ramrao Adik Institute of Technology, Nerul, Navi Mumbai 400706, India
[2] Department of Electronics Engineering, Ramrao Adik Institute of Technology, Nerul, Navi Mumbai 400706, India
agarwal.shivangi@gmail.com
[3] Department of Instrumentation and Control Engineering, NSIT, University of Delhi, Sec-3, Dwarka, New Delhi 110078, India
https://www.rait.ac.in, http://www.nsit.ac.in/

Abstract. Osteoporosis means porous bone. If a healthy bone is looked under a microscope, it will look like a honeycomb. In case of osteoporosis, the holes and spaces in the honey comb are much larger. This means bone has lost its density. As bones become less dense they tend to break easily, the bones of the spine are at great risk. This paper is the part of the project which designs and develops a bone mineral density (BMD) detecting ultrasound machine. The unit is fully compact and portable and enables the BMD to be evaluated in real time by determining a parameter known as net time delay (NTD). Computer simulations are used to compare dependencies of NTD and BMD. It shows that the dependencies are very high. Hence concluding that NTD is highly proportional to bone mass and machine learning approach can be used to estimate the BMD of the subject. Looking to the severity of the disease and availability of expertise with ultrasonic system, it is proposed to develop low cost Ultrasonic based Bone Densitometer system to find the NTD thus the density of the bone and then find the T-Score in medical terms using Linear regression model.

1 Introduction

Bone density, or bone mineral density (BMD), is the quantity of bone mineral in bone tissue. The concept is of mass of mineral per volume of bone. Improper BMD can cause Osteoporosis i.e. “porous bone”. Artificial intelligence has been on the Radar of technology leaders for decades and these autonomous machines can help us making decisions or carry out complex tasks. Machines can do complex and stressful work faster than Human multiple task at a time. So in order to get appropriate data and accurate result, AI has been used. Current existing system for bone densitometer scanning uses X-rays, hence it is costly. Also, the size and weight of such a system is massive. Using X-rays might have some side effects on a person’s body. So, to avoid all these problems a new idea of using

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Ultrasonic sound for measuring the bone density is used. Bone density can be easily calculated using the difference between sound intensity at two different points. This system can be made handy, as size of the equipment needed isn't large. Also, it's setup is easy as compared to X-ray based system. So, in order to provide neat and elegant solution, we decided to use Ultrasonic sound based scanning system.

1.1 Purpose and Problem Definition

Osteoporosis is a major health related issue, endangering human lives, in turn causing collateral damage to various entities. Bone density importantly influences our lives. Apriori accurate detection of low bone density is a key that could prevent any further damage due to Osteoporosis. Powerful computational tools are needed for predicting the accurate result of low bone density. There is a need of compact and reliable system for predicting the proper bone density related issues. A branch of AI i.e. Machine Learning has many advantages like experiential prediction to produce optimal results in reasonable amount of time, suitable for predicting output by taking past results into account, so proposed system is based on Machine Learning to predict and categorize the bone density.

1.2 Scope

Bone density index prediction is a crucial issue when fighting with Osteoporosis. A direct prediction of person to have Osteoporosis or not cannot be determined by seeing results, as there are some cases in which even if bone density is low, chances of Osteoporosis are less. So, to neatly predict close to accurate results, machine Learning algorithms like Linear Regression are used. This reduces the uncertainty in output prediction and reduces false predictions. An intelligent system based on Machine Learning algorithms has been implemented for prediction of Osteoporosis.

2 Literature Survey

In [1], Normative information on BMD and body structure measured with dual energy x ray absorptiometry (DXA) were acquired from early age to adolescence. The most easily available and most frequently uses method for measuring BMC and BMD in kids is DXA. The major benefits of this method are its brief time, very small dose of radiation, high precision, and the capacity to evaluate BMC and BMD at both axial and appendicular skeletal locations. This article proposed that before the end of the second span of 10 years, there is a slight rise of the skeletal mass in the lumbar spine and complete body. This research offers reference value for kids and young adults for bone density and body composition measured with DXA.

In [2], The article writer has introduced a device that is completely mobile, light and allows the BMD to be assessed in live time by determining a variable

known as NTD. The NTD is described as the difference between the travel period of an ultrasound signal via the heel and the travelling time through an equally thick (to the heel) hypothetical item but comprising only soft tissue. Author's information shows that the fresh instrument and its related ultrasound parameter, the NTD, are highly susceptible to bone mass as measured by DXA scanners. On the other hand, the information demonstrate that the velocity of the ultrasound is much less correlated with BMD, this is due to differences in the quantity of overlying soft tissue density and calcaneus density between individuals. In short, a fresh instrument has been defined which, in specific, has the ability to widen the range of ultrasound application and bone screening in general.

In [3], The writer outlined the bone mineral density test in detail. X rays are utilized to evaluate the mineral quantity in bone. This test is essential for individuals having high potential of osteoporosis, particularly females and older adults. Also called as DXA. It is an significant test for osteoporosis.

In [4], Many efforts have been taken towards enhancing the quality. However, the presence of reliable BMD prediction techniques is still scarce, and they hardly include a real-time analysis simulation module. The main reason for this lack of confidence in prediction is uncertainty in prediction. Past attempts have made a direct prediction of person to have Osteoporosis or not by seeing indexes, which cannot be determined like that, as there are some cases in which even if bone density is low, chances of Osteoporosis are less. Also, as X-ray based systems are tedious to setup and are massive due to X-ray emitter systems, it is troublesome to take them far remote and rural areas. Similarly many researchers have worked in this area [5–8].

2.1 Benefits of the Proposed System

The solution to the problem defined above requires a system based around a model that can predict and categorize the bone density with improved accuracy despite the uncertainty in the input parameters involved. ML does exactly that. Using only data related to bone densities under analysis and also past data, algorithm can produce results in a reasonable amount of time, and is also suitable for parallel processing. The main advantages of the Proposed System are:

1. Improved accuracy of Results: Algorithm has the ability to produce "closer to optimal" results. This leads to a better intuition of the possible category of bone density.
2. Quicker Predictions: The system can make predictions in a "reasonable amount of time" while also "supporting parallel processing", which results in quicker predictions and timely actions to respond to the situation with a proper strategy.

3 Proposed Methodology

3.1 Module Description

As Net Time Delay (NTD) of ultrasound and Bone Density (BD) are correlated, a Linear Regression model can be used for predicting BD according to NTD. Linear Regression is a method to predict the dependent variable (Y) based on the values of independent variables (X). It can be used for the cases where we want to predict some continuous quantity (Fig. 1).

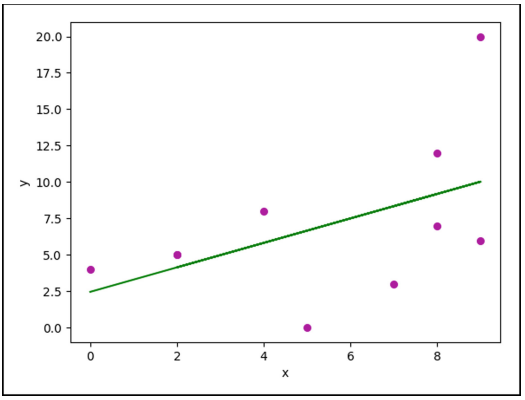

Fig. 1. Representation of linear regression (Color figure online)

Here the X axis is called independent axis, which will be plotted with NTD data. Y axis or dependent axis will be plotted with BD data. Regression line (as shown in blue) will be plotted optimally for all points. As it is assumed that the two variables are linearly related. Hence, we try to find a linear function that predicts the response value (y) as accurately as possible as a function of the feature or independent variable (x). The equation of the regression line is represented as: $\mathbf{y = b0 + b1 * x}$.

Linear Regression to convert the Net Time Delay to Bone Density:

```
import numpy as np
def estimate_coef(x, y):
    n = np.size(x)
    m_x, m_y = np.mean(x), np.mean(y)
    SS_xy = np.sum(y*x - n*m_y*m_x)
    SS_xx = np.sum(x*x - n*m_x*m_x)
    b1 = SS_xy / SS_xx
    b0 = m_y - b1*m_x
    return(b0, b1)

def Predict(NTD):
```

```
    # observations sample random
    x = np.array([0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4])  #
    taken test data [2]
    y = np.array([0, 0.4, 0.6, 0.8, 1, 1.4, 1.6, 1.8, 2])
    #taken test data [2]
    b0,b1 = estimate_coef(x, y)
    print("The estimated value of b0 = " + str(b0))
    print("The estimated value of b1 = " + str(b1))
    BD = b0 + b1 * NTD
    print("The estimated value of Predicted Bone Density =
     " + str(BD))
Predict(0.04)
```

Listing 1.1. Linear Regression

Output:

```
    The estimated value of b0 = -0.004395604395604602
    The estimated value of b1 = 0.5355311355311357
    The estimated value of Predicted Bone Density =
    0.017025641025640827

```

Thus now, we have got the prediction about bone density for given NTD. The data used is of a male's lumbar spine bone density, age between 18–23 [1] (Fig. 2).

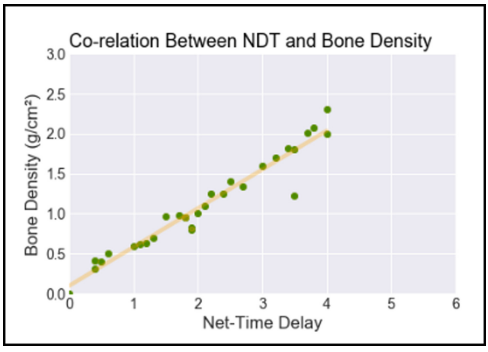

Fig. 2. Correlation between NTD and Bone Density

We have simulated a population mean here, after analyzing the real data we will get the real population mean.

```
t_score = (BD - popu_mean)/(std_dev/math.sqrt(sample_size
    -1))
```

Where BD is predicted value of BMD and `popu_mean` is the mean of population or data set taken for analysis.

```
t_score = -3.851155020921751
```

3.2 Hardware and Software Requirements

1. Software Requirements
   - Operating System: Any OS with Python support
   - Platform: Python 3.5 or above pre-installed with data analysis modules
   - Python libraries used: numpy, scipy, matplotlib
2. Hardware Requirements
   The hardware required for data collection is out of the scope of the project
   Computational hardware required
   - Minimum 4 GB RAM on system
   - Processor with high clock rate
   - USB input peripheral should be available

We will collect the data via a digitizer using PyUsb, do the computing on the NTD and calculate the bone density to get the T-Score.

4 Project Results

The system is trained with data obtained from a male's lumbar spine bone density, age between 18–23. [1]

For value 0.04 as test value, we get
Predict(0.04)
Output:

```
The estimated value of b0 = -0.004395604395604602
The estimated value of b1 = 0.5355311355311357
The estimated value of Predicted Bone Density =
    0.017025641025640827
```

We've got the prediction about bone density for given NTD. We will use this BD to obtain the statistical T-score for given density. A healthcare provider looks at the lowest T-score to diagnosis osteoporosis.

According to the World Health Organization (WHO):
Normal bone density range has T-score of −1.0 or above.
Low bone density or osteopenia has T-score between −1.0 and −2.5.
Diagnosis of osteoporosis has T-score of −2.5 or below.
Based on T-score, we can predict the category of bone density found for given bone sample, hence can predict chance of Osteoporosis.

```
t_score = (BD - popu_mean)/(std_dev/math.sqrt(sample_size
    -1))
```

Where BD is predicted value of BMD and `popu_mean` is the mean of population or data set taken for analysis.

```
t_score = -3.851155020921751
Your t-score is below -2.5, you have Osteoporosis
```

5 Benefits of Proposed System

The system in its current form can accurately categorize whether the person is having Osteoporosis or not, depending upon the NTD value obtained from Ultrasonic Transceiver system.

1. Accuracy: As the relation is found to be linearly regressive, it's easy to get required BMD index and hence t-score from it, to predict.
2. Speed: Once trained with given dataset, system can map any NTD value to BMD value and can predict Osteoporosis very easily.
3. Cost Effectiveness: As this system uses Ultrasonic transceiver instead of classical X-Ray based heavy systems, not only the maneuvering cost, but the cost of operation also gets reduced.

6 Conclusion

The aim of the proposed system has been achieved. A well trained system can now predict Osteoporosis accurately in low cost operations. The ease of calculation is possible due to Linear Regression algorithm used for prediction. Trained well enough for accurate dataset, it provides neat and accurate basis for calculation of BMD value. Apriori detection of Osteoporosis can now be done easily to improvise doctor's diagnostics.

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