Comparison of different metrological devices used in biomedical applications

Ryniewicz Andrzej, Gaska Adam
Laboratory of Coordinate Metrology, Department of Mechanical Engineering, Cracow University of Technology, al. Jana Pawla II 37, 31-864 Cracow, Poland
andrzej@ryniewicz.pl, agaska@mech.pk.edu.pl

Abstract. Thanks to the progress in examination of human body, it is possible to create new methods of diagnostics. To diagnose diseases properly, one should recognize the internal and external structure of organs, their geometrical parameters, width, height, etc. And this is a place, in which cooperation between coordinate metrology and medicine is the most strong. Metrological devices could be used in this area, in a variety of uses. Paper shows usage of Coordinate Measuring Machines (CMM) and Coordinate Measuring Arms (CMA) in determination of external structure, dimensions and shape of measured objects (part of bones and joints). Also use of Computed Tomographs (CT) in medical applications will be presented. Then the comparison of results of measurements performed on each device will be made. Apart from this, article puts attention on practical meaning of results obtained from CT measurements. Problem of the shape mapping and its accuracy will also be discussed.

1. Introduction
Metrology is a science, which solves problems concerning measurements from almost all kinds of sciences: technological, environmental or medical. Nowadays, there are still more and more uses of coordinate metrology in biomedicine and connected with it measurements of live beings organs geometry. This is why there is a need to focus on opportunities which biomedical metrology gives.

Thanks to the progress in examination of human body, it is possible to create new methods of diagnostics. To diagnose diseases properly, one should recognize the internal and external structure of organs, their geometrical parameters, width, height, etc. And this is a place, in which cooperation between coordinate metrology and medicine is the most strong. Metrological devices could be used in this area, in a variety of uses. Thanks to Coordinate Measuring Machines (CMM) and Coordinate Measuring Arms (CMA) it is possible to determine external structure, dimensions and shape of measured object (for example part of bone or joint). When it is impossible or not advised to measure objects with use of touch probes they could also perform measurements in optical way, without physical contact with it. On the other side, Computer Tomographs (CT) despite of external surface of organs could perform measurements of its internal structure.

In this article the description and methodology of use of mentioned devices, in medical applications will be presented. Usage of them will be presented on example of real medical measurements. Also the comparison of results of measurements performed on each device will be made. Apart from this, article puts attention on practical meaning of results obtained from CT measurements. Problem of the shape mapping and its accuracy will also be discussed.
2. Metrological devices used in medical applications

2.1. Coordinate Measuring Machines

The basic tool for coordinate measurements are Coordinate Measuring Machines. CMMs are machines whose kinematic structure realize moves in three perpendicular directions (x, y, z in Cartesian System). They could also be used in biomedical applications, and their accuracy are the strongest point in this usage. Some of them (for example PMM Leitz 12106 machine, which practical application will be presented in this paper) give possibility to measure objects with uncertainty less than 1µm. It is also possible to scan the measured surface by using scanning probe head.

![Figure 1. Measurement of joint performed on Leitz 12106](image)

Measurement of knee-joint, by scanning chosen surfaces, were performed on Leitz 12106 PMM characterized by uncertainty equation:

\[ U = 0.8 + \frac{L}{400} \, [\mu m] \]

Results were then analyzed in 3DReshaper software. Results from CMM are the most accurate from all devices presented in this paper and this is why they were taken as a reference results. In fig. 2 the results of measurements on the CMM in the form of the points being control lines and created surface representing the reference 3D model of the knee condyles are presented.

![Figure 2. Measuring points performed on CMM and the surface of knee condyles](image)

2.2. Coordinate Measuring Arms

Coordinate Measuring Arms are machines that are equipped with several rotary axis (usually six) and in each axis there is an encoder that measures the rotary position of the axis. Knowing the geometrical construction of arm and the rotary positions of axes we are able to determine the midpoint of tip probe, which is itself the result of single measurement. Coordinate Measuring Arms allows touch measurements but also optical measurements (thanks to scanning cameras like G-SCAN or RX2 Scan).

Measurements of joint on CMA armed with RX2 Scan head were also performed (fig. 3) and results were compared to other methods.
Figure 3. Measurements performed on Omega Arm with use of scanning head RX2 Scan

Examplary results of measurements of hip-joint are presented on figure 4.

Figure 4. a) Surface being a result of measurements performed on Omega Arm with use of scanning head RX2 Scan, b) points obtained by scanning on Leitz PMM 121006 machine

2.3. Computed tomography

Computed tomography is one of the latest techniques of diagnostic and therapeutic mapping, and is particularly important because of the increasingly common use of this method in medical and technical applications. In technical applications computer tomography allows to control not only the geometrical parameters of products, but also allows to penetrate into the interior of the test object and evaluation of its internal structures.

Measurements of knee joint were performed also on this device. Than a CAD model of knee were created on Amira software and compared to other methods. Results of this comparison are shown on fig.5 and fig.6.

Figure 5. Knee-joint - the imposition of measuring points from CMM on the surface obtained from measurements on CT using the 'best fit' method.

The map of accuracy deviations of shape mapping on CT is shown in figure 6. It was found that 80% of the deviation of the mismatch does not exceed ± 0.5mm. Maximum values (up to ± 3 mm) occurred in the area of the junction of both surfaces of condyles and on the tips of the condyles. There were positive deviations (65%) and negative (35%).
3. Accuracy of shape mapping

The problem of the accuracy assessment of the shape mapping of bioelements, particularly cartilages and bone tissues and their internal structures is extremely important. The scientists are fascinated by this problem for many years in various fields. Recent mapping techniques such as spiral computer tomography (SCT) and magnetic resonance (MR) solve that problem partially, but still geometry designation creates many problems. These techniques do not allow, at a specified measurement uncertainty, the simultaneous appointment of the geometry of bone and cartilage structures in the whole research area. This issue is particularly important for assessment of the size and diagnosis with osteoarthritis.

Hypothesis may be that the provision of shape mapping of the joint surfaces with sufficient accuracy, allow for evaluation of a small loss of cartilage, chondromalacia, and for designation the spatial shape of the buccal cartilage and assessment of its impact on the operating conditions of biobearing.

The accuracy assessment of shape mapping using synthetic indicators, which are the functional combination of the errors of selected teams of evaluated device or characteristic points was proposed.

Error values were determined as the difference between the vectors defining the location of characteristic points of the artifact and the resulting model in the adopted reference system. In the case of determining the accuracy of the mapping of working surfaces of joints using the STK or MRI, which in principle are the areas of irregular shape, the algorithm procedure was developed which allows for a direct comparison of 3D image of the test area and the numerical model (where there is a mathematical description) or negative model obtained from other measurement techniques. The main units of the system are blocks: blocks of visualization and data collection and blocks of analysis of vector error comparison.

3.1. Analysis of the accuracy of shape mapping using ceramic balls

The analysis of accuracy of the shape mapping using computer tomography (CT) was performed for two cases: based on ceramic reference ball (fig. 7) and the natural artifact - the knee joint. Here the results of the first mentioned analysis will be presented.
Measurement strategy included series of 3 cycles of measurement, and for balls in addition to the two perpendicular orientations.

Measurements were performed on the CT (fig. 7). The accuracy assessment of the shape mapping of the sphere was carried out based on the ball numerical artifact [4].

In the case of a natural artifact measurements were performed on Siemens tomography and on the coordinate measuring machine (CMM). In the accuracy assessment of the mapping of knee joint using technique of CT, reference element was developed on the basis of the results of measurements performed on the CMM. The results of tomography research and analysis of accuracy of the shape mapping using 'best fit' method and the program 3D Reshaper. The measurement results were presented as: the mapping deviations of the surface of ceramic reference ball resulting from the errors of measurement performed on computer tomography in the side view in figure 8, the mapping deviations of the surface of ceramic reference ball resulting from the errors of measurement of the radius performed on computer tomography - a view in the polar axis of CT computer (Fig.9). Figure 9b presents also wavy surface on the 3D model, which was obtained in the vicinity of the pole CT.

![Figure 8](image1.png)  
Figure 8. Mapping deviations of the surface of ceramic reference ball resulting from the errors of measurement performed on computer tomography in the side view and transparent view.

Figure 10 is the histogram of the distribution of errors of the radius measurements of ceramic reference balls resulting from measurement on CT.

![Figure 9](image2.png)  
Figure 9. a) Mapping deviations of the surface of ceramic reference ball resulting from the errors of measurement of the radius performed on computer tomography - a view in the polar axis of CT, b) wavy surface on the 3D model in the vicinity of the pole CT

Histogram of errors of the radius measurements of reference ball was based on 10,000 measurements. The studies allow the conclusion that for 90.7% of the results the error of radius measurement of the ball using CT is located in the range of ± 0.063mm, and for 98.5% falls within ± 0.125mm. The standard deviation is 0.0428mm, and the average value of ball diameter is 24.969mm.

Image analysis of so. CT poles demonstrates the distortions of a ball surface resulting from a change in the angle of ball surface with the scanning plane (fig.11), with the possibility of determining the width of the scan.
Figure 10. Histogram of the distribution of errors of the radius measurements of ceramic reference balls resulting from measurement on CT

Figure 11. Tomography poles in the resulting 3D model of the reference ball

4. Conclusion
Presented results shows that the development of coordinate techniques allows measurements and examination of live beings organs in more comfortable way. Thanks to measuring utilities and modern software solutions it is possible to analyze the accuracy of shape mapping of various bioelements performed by different coordinate techniques.

However, nowadays CT is still the most frequently used device in medical examination of different organs. The main reason of this situation is that CT allows measuring objects in non-contact manner and it also allows to diagnose the inner structures of measured organs.

This is why the accuracy of shape mapping performed by CT is so important. Authors shows the method of estimation of this accuracy. Developed system allows for the evaluation of devices based on CT and to determine the quality of the entire device based on the dominant parameters or characteristics with respect to their function or according to some teams. At the same time the system can be used to compare the number of functionally similar devices from the perspective of selected properties or performance characteristics. Determination of synthetic indicators allows for the designation of the influence of selected parameters (geometric or kinematic) on the analyzed characteristics of utility. The system has a modular construction, it can work with any measuring device equipped with an interface allowing data transfer to computer control and evaluate the device.

References
[1] Flohr T. et al.: Performance evaluation of a 64 slice CT system with z-flying focal spot. Fortschr. Rntgenstr 2004, 176 1803-1820.
[2] Hofer M.: Teaching Manual of color duplex tomography, 2nd edition, Tieme, New York 2004.
[3] Ryniewicz A.: Traceability needs for geometrical identification of form of biobearing working surface and defect of joint cartilage, Wydanie ELSEVIER MEASUREMENT ISSN 0263-2241, vol 42. nr10. 2009 page 1463-1469, meas. nr 1198.
[4] Cierniak R.: Computed Tomography. Algorithms of reconstruction, Warsaw 2005.