EVALUATION OF A MAGNETIC 3D MEASUREMENT SYSTEM FOR APPLICATION IN COMPUTER ASSISTED SURGERY COMPARED TO ESTABLISHED OPTICAL TRACKING SYSTEMS

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Abstract

3D measurement systems are essential components for applications in computer assisted surgery to permanently acquire the spatial position of surgical instruments with regard to the patient's anatomy. The accuracy of these systems is of crucial importance. Unfortunately manufacturers only provide guaranteed error limits and only in very few cases error distributions in measurement volumes. This lack of information prevents the use of those systems in several applications.

In this work a tailor made experimental setup to solve this problem introduced by [1] was adapted for magnetic trackers to evaluate the accuracy of markers with a cheap and flexible environment to produce sufficiently precise and reproducible data to generate calibration maps for the requested measurement volume. Objects of different size and material have been introduced into the measurement volume to identify backlash on the detected positions and to check if a basic calibration based on the gathered information is possible.

1. INTRODUCTION

Some surgical tasks require precise feedback from trackers inside the human body, especially if this feedback is the only one the surgeon will get. This feedback gets really crucial if it is also used to control manipulators as it is done in the EU funded project Stiff-Flop (STIFFness controllable Flexible and Learn-able Manipulator for surgical OPerations, http://www.stiff-flop.eu). This project aims at the design of a flexible and stiffness controllable octopus-like robot that can go through narrow openings and manipulate soft organs. Controlling such a hyper-redundant system faces a lot of issues like distributed sensing (tactile as well as position), cognitive development and a reliable feedback. Possible surgical 3D tracking systems are available on the market; unfortunately it is not possible to compare them directly in terms of accuracy because manufacturers only provide guaranteed error limits under special conditions and in different measurement volumes. This initial situation made it necessary to find a platform that enables the user to find the best solution for his special application.

2. SPECIFICATIONS

The requirements for such a system are set by a number of factors. First of all the measurement system shall guarantee sufficient precise results; a resolution better than 5µm is intended. Along with this demand comes the necessity of reproducibility. In addition the system has to be flexible enough to handle different kinds of tracking systems available on the market and to deliver comparable results. Last but not least the system has to be affordable and handy to use.

3. THE SETUP

All these points are fulfilled by the system introduced by [1]. The authors developed a tailor made experimental setup to meet all those requirements for Optical 3D measurement systems. It evaluates the accuracy of marker based localization systems and displays the results in an intuitively understandable way. The basis here is a LEGO® brick base plate which has been fixed on a rigid aluminium board and calibrated by a high precision coordinate measuring machine afterwards. This approach seems appropriate, because the LEGO® system provides well usable equipment with high precision; the official production tolerance declared by the manufacturer is 2 µm.

The existing system had to be modified a little bit to get it running with the magnetic measurement system (NDI Aurora V2), because the aluminium plate prevented the system from working at all. The sensors were detected at a minimum distance to the board of about 10 cm. Therefore a new LEGO® plate was mounted on an acrylic polymer board. The surrounding area was freed from any kind of conductive material, only the mounting of the field generator (medical steel) is kept because it belongs to the equipment provided by the manufacturer. The setup is shown in figure 6.

The position and orientation of markers at defined positions in workspace have been recorded relative to a fixed marker, which is used to eliminate possible vibrations of the mounting device holding the field generator and to monitor that no other external influence disturbed the measurement. This has been done one hundred times for each position and a median filter was applied in order to reduce noise and point out deviations from the original position.

As a first step these results were compared to optical tracking systems (Axios Cambar B2, NDI Polaris). The second step was the introduction of objects of different size and material into the measurement volume to identify backlash on the detected positions and to check if a basic calibration based on the gathered information is possible. All experimental arrangements have been examined several times to check and prove the reproducibility of the results.

The software is implemented in LabView and split into three major parts: One LabView program to establish a connection to the various tracking systems (including data conversion if necessary), one to record positioning data of markers and trackers and a third one to evaluate the recorded data and display the results in an intuitively understandable format. The whole system is designed in a modular way to guarantee extendibility without the danger of incompatibility between existing versions.

The software package is able to determine, compare and evaluate the Fiducial Localization Error (FLE, distance between actual and measured position of a single marker), Fiducial Registration Error (FRE, root-mean-square error in fiducial alignment between image space and physical space) and the Target Registration Error (TRE, similar to FRE, but for a tool centre point not located in the median point). Details about these error definitions can be found in [2]. For this investigation only the FRE is considered, because the small size and the shape of the sensor make it unnecessary to place it far away from the tool centre point of the device that is going to be monitored.

4. ACCURACY

The aurora tracking system offers two different measurement volumes: a smaller "cube" and a slightly bigger "dome" volume. The manufacturer provides error limits for both volumes, divided into "Position accuracy", "Position Precision" and "Position Trueness". The tracking mode has to be selected before start of tracking. At this point it is not clear if the decisive factor for those limits is the tracking mode or the position of the tracked object. In addition the error limits given by the manufacturer are based on [5] and not showing the accuracy of a single measurement but the mean of a "large number" – the amount is not specified.

According to [5] "Trueness" refers to the closeness of agreement between the arithmetic mean of a large number of test results and the true or accepted reference value, whereas "Precision" refers to the closeness of agreement between test results.

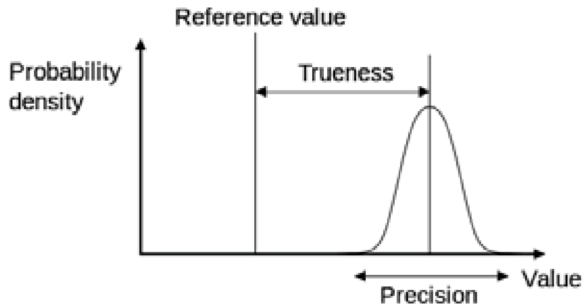

Fig. 1. Definition of "Trueness" and "Precision". Image is taken from [5]

The first experimental setup will have a look at the range of a single measurement and the impact of switching the measurement volume. Unfortunately we are only able to get information about the precision, not the trueness of the system, because the base frame is inside the field generator and cannot be accessed from outside.

Six defined positions were measured once in cube and once in dome mode. For each parameter set repeated measurements were conducted and the values were appended to achieve a total of 1000 values. This also proves the reproducibility of the measurement. An example of a single position measurement can be seen in figure 2.

The figure shows 1000 measurements of a point located at a position near the edge of the cube volume and about 350mm (z direction) away from the field generator. Figure 3 shows a histogram of the spatial deviation shown in figure 2:

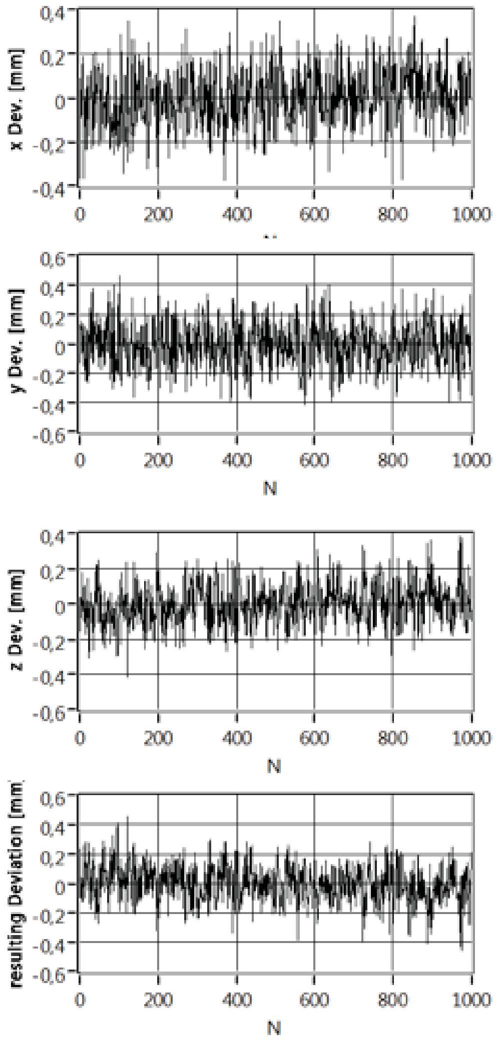

Fig. 2. Measured values in x, y and z direction and resulting deviation in space

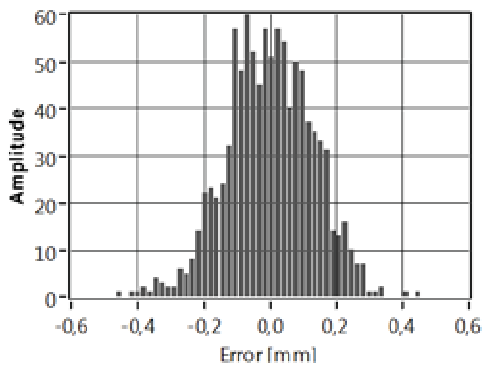

Fig. 3. Histogram of measurement series

The identified standard deviation for this example was 0.1289 mm.

The results of this experiment are diverse: First of all we can say that the standard deviation gets bigger at an increasing distance to the centre of the field generator in z direction as well as in x and y. Surprisingly the precision for sensors in the cube volume gets better if the operation mode is switched to "dome volume". This behaviour could not be illuminated at this stage of the current research work.

Another interesting point to look at would be the trueness of the measurement for different positions in workspace. Unfortunately an absolute comparison for single markers is not possible because the internal base frame of the field generator cannot be accessed from outside. The only way to get an idea of attainable trueness is to match known positions on the reference board to positions detected by the tracking system. In our case this point cloud matching is done based on an algorithm developed by [4]. The negative aspect of this procedure is the minimization of the errors at all measured positions – it is not possible to detect offsets of the whole point cloud.

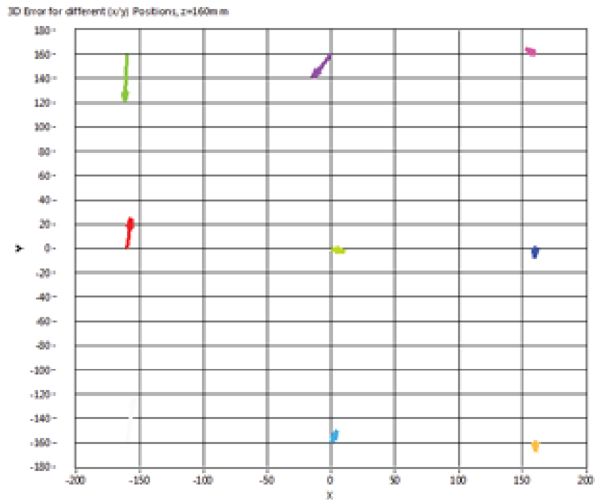

Fig. 4. 3D Error on a plane in cube volume, distance to field generator z=160mm. The vectors show the direction of the deviation and have been scaled by 2000. Unit is [mm]

The absolute deviations for an example plane (z=160 mm) after the matching can be found in figure 4. The vectors have been scaled by 2000 to make them visible.

The size of the absolute error in space is shown in figure 5.

5. RELIABILITY

The reliability of a tracking system is mainly determined by its robustness to external influences. Fortunately a magnetic tracker is not influenced by occlusion or changing lights as optical trackers are, but there might be other perturbations like external electro-magnetic fields or electrically conductive material nearby or inside the measurement volume.

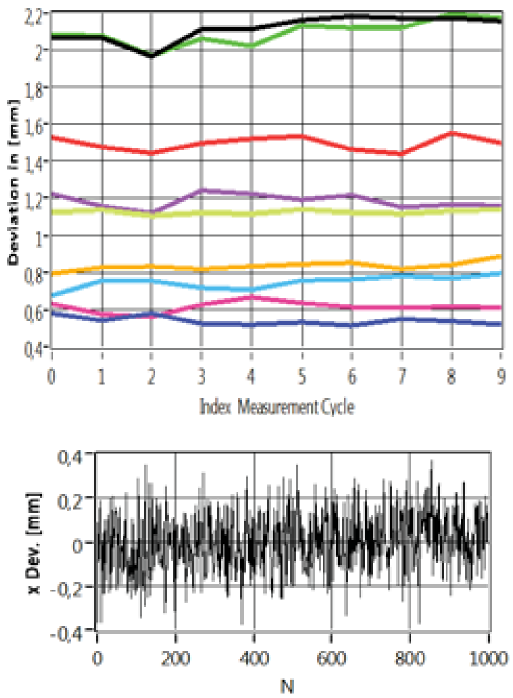

Fig. 5. Absolute deviation of all nine locations shown in Fig. 4. Unit is [mm]

To gain insights we tried to influence the system by objects of different size and material, starting with a huge brass tube in a distance of 400mm in y-direction to the centre of the cube volume (Figure 6). After 500 measurements the object had been moved to a distance of 300mm. Additional 500 measurements have been taken.

Fig. 6. Test with brass tube

The results can be seen in figure 7: All detected sensor positions moved into different directions, some of them up to 24 mm. Surprising was also the behaviour on the z-Axis (Figure 8): Deviations of up to 9mm were possible, although the tube still stood outside the measurement volume.

A possible explanation of this behaviour would be the generation of eddy currents in the electrically conductive material, disturbing the electromagnetic field of the generator.

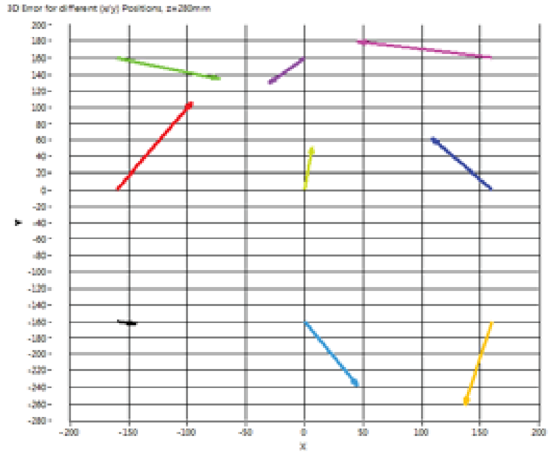

Fig. 7. Deviation of nine detected sensor positions in cube volume after placing a huge brass object beside the setup. Vectors have been scaled by 2000 to make them visible. Unit is [mm]

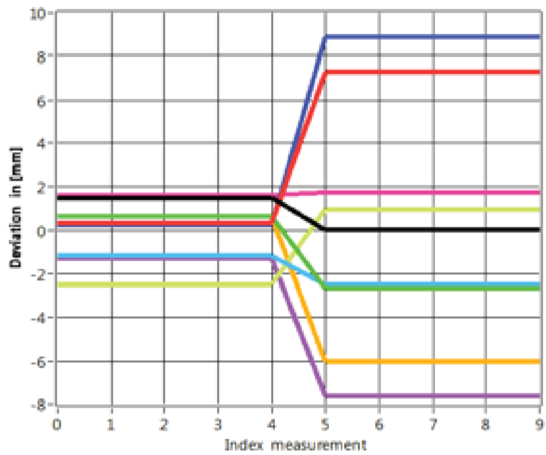

Fig. 8. Deviation in z-direction for the above shown sensor positions. After 500 measurement cycles the object has been moved closer. Unit is [mm]

The results and the possible explanation were verified by removing the tube and placing a small conductor loop inside the cube volume (diameter about 280mm, two coils). The results were not directly comparable because of the size and the position of the objects, but it was noticeable that also the loop had quite some impact on the accuracy. The expected effect of a "bundled" or "compressed" electromagnetic field in the centre of the cube volume is visible in figure 9 and figure 10 below. The first 500 measurements were made without the coil, the next 500 with it.

Quite unexpected was the result for the dimension of the deviation in space: Eight of nine sensors reported more accurate after inserting the coil.

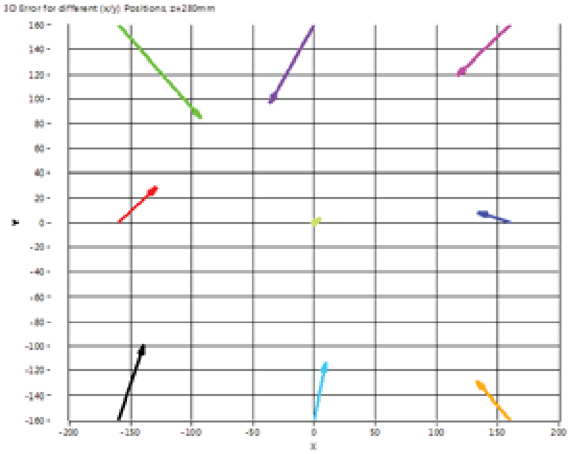

Fig. 9. Deviation of detected sensor positions in cube volume after placing an electrically conductive coil in the centre of the dome volume. Vectors have been scaled by 2000 to make them visible. Unit is [mm]

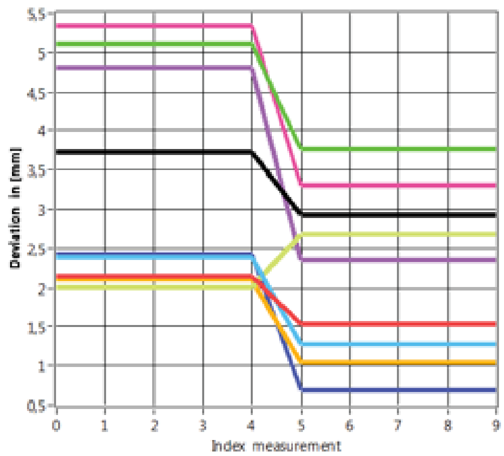

Fig. 10. Spatial deviation for the above shown sensor positions. Unit is [mm]

7. CONCLUSION

The magnetic system has demonstrated unexpected stability in the periphery of electromagnetic disturbances like connecting smartphones within the workspace. On the other hand we were able to identify critical situations when electrically conducting material was placed near the measurement volume. In some cases absolute and relative values showed quite unexpected results that need further investigation.

The desired goal to create a calibration algorithm for a magnetic tracker could not be achieved at this stage of work, because in our envisaged application we will not be able to refrain completely from electrically conductive material and the influence of those materials in range of the field generator is not neglectable und quite unpredictable. Although optical tracking systems suffer from other ambient conditions like illumination, higher distance to the measured object and target registration errors because of bigger locator geometries, they seem to be more suitable for high precision tasks in unknown environments. Another advantage is the bigger measurement volume of many optical systems. The big advantage of the magnetic tracking system is the small geometry of the sensors and the possibility to use the markers in an isolated space if the hull is made of non-conductive material.

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