

System for Vestibular Examination based on Kinect Sensor

Viliam Dolinay, Lucie Pivnickova, and Vladimir Vasek

Abstract— The purpose of this research is to verify the ability of of modern game device such a Microsoft Kinect sensor for examinations in otoneurology. One of the traditional tests - Hautant's test, was selected and its implementation based on Microsoft Kinect skeleton tracking feature will be presented. Hautant's test has been programmed for laboratory experiments and the results are discussed and tested in cooperation with specialists in otoneurology. However, otoneurology has several other tests that are based on spontaneous or artificial unbalance human movement tracking. The combination of Kinect sensor and future software application therefore appear to be further applicable with possible benefits in practice. Using gaming equipment can also greatly accelerate the development. The research does not need to focus on the hardware development and the efforts may be directed to the implementation of the particular task. The objectives and results may be earlier deployed for practical tests and use. The price of the hardware, which is produced in the millions series for gaming devices is of course much lower than the equipment developed specifically for particular medicine examination. Nevertheless, to enforce any new device into practical use, especially in medicine is a complicated process and will require a lot of effort which will still need to spend.

Keywords— Balance, dizziness, Hautant's test, medical examination, Kinect, vertigo.

I. INTRODUCTION

THE modern technology has often gotten into wide use over military developments, such as GPS system. Another sector that is indirectly pushing development is the gaming industry. The effort to constantly offer new features to satisfy the users and compete in the business competition requires constant development.

The development of new sensors brings opportunities to revive, modernize and especially objectify the tests from medicine, which were originated many years ago. The situation is similar in most fields of medicine, as indicated in [7, 8].

This work was supported by the European Regional Development Fund under the project CEBIA-Tech No. CZ.1.05/2.1.00/03.0089)

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This paper introduces way of linking two areas - gaming devices and diagnostic methods in medicine. For this purpose the Microsoft Kinect game control device was used to perform examination of human stability. Using existing hardware solutions have been great benefit. Development of own device requires a number of steps [5], when using existing hardware may not be completed. However it was necessary to become familiar with Kinect functions and features, test it, prepare algorithms evaluating measurement results and also visualization of outputs had to be adapted to the habits of medical practice. Similar solutions for vestibular examination are also developed based on Wii Balance board [4, 6].

First step of development was greatly facilitated and the first results quickly showed show the possible advantages and weak points of this approach.

II. HUMAN STABILITY TESTS

Instability is a common symptom which arises during the life of almost every one of us. For example some surveys in US show that more than 40 percent of Americans will experience dizziness/vertigo that is serious enough to go to a doctor. Even dizziness that seems minor, if undiagnosed, may be a signal of underlying disorders. Dizziness/vertigo problems are among the most common reasons that older adults seek help from a doctor. Many people are surprised to learn that the source of their dizziness may be because of an inner ear or vestibular problem. Dizziness due to a vestibular dysfunction are reported in about 9 percent of the population who are 65 years of age or older. Fall-related injuries due to dizziness or imbalance such as breaking (or fracturing) a hip are a leading cause of death and disability in older individuals. Some dizziness and balance conditions are also due to neurological conditions like Multiple Sclerosis, Parkinson's Disease, Brainstem strokes (TIA), and Cervical vertigo. Other miscellaneous conditions that cause dizziness and balance problems can be psychological disturbances, post-traumatic vertigo, and post-partum vertigo [16].

Medical science has gradually defined series of tests allowing assessing the cause of dizziness, determining their type, severity, etc. It should be noted that individual tests always reflect technical resources of its time and the new technical means of new age always allowed improving and

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refining these tests.

The balance disorder tests are frequently based on the monitoring of human movements. The examined person is put into a state off-balance, such he/she is asked to stay or to perform some action with closed eyes, on one leg, etc. and particular test evaluates deviation of the patient body from the measurement starting point. The evaluation of these tests requires obtaining an objective, numerical expression of results, usually are measured angles and length. Traditional ways using protractor and ruler is evidently a laborious activity and currently quite obsolete. It is a task and responsibility of engineers to revive these tests and offer modern and efficient evaluation methods.

Example of such test is measuring person stationary stepping with closed eyes by Unterberger 1938 or Fukuda 1959, later modified as CCG (Craneo-corpo-graphy) test in 1968 [1, 2]. Another test based on the tracking of the body is Hautant's positional test [9]. This test was selected for pilot implementation and will be discussed in the *Implementation* chapters of this paper.

III. KINECT FOR WINDOWS

The device used in this work is Microsoft Kinect sensor. It was introduced in 2009 for the Xbox game console and in 2011 was inducted version for Windows with own software development kit [10]. Device is shown on fig. 1. In 2013 was introduced the next generation of this sensor (in work is not used yet).



Fig. 1 Kinect for Windows [10]

This device among others provides the skeleton tracking feature that is used for the implementation of the above mentioned otoneurology test.

A. Device features

The Kinect for Windows sensor shares many of the core capabilities of the Kinect for Xbox 360 sensor, including [10]:

- 1) An RGB camera that stores three-channel data in a 1280 x 960 resolution at 12 frames per second, or a 640 x 480 resolution at 30 frames per second. This makes capturing a color image or video possible.
- 2) An infrared (IR) emitter and an IR depth sensor. The emitter emits infrared light beams and the depth sensor reads the IR beams reflected back to the sensor. The reflected beams are converted into depth information measuring the distance between an object and the sensor. This makes capturing a depth image possible.
- 3) A multi-array microphone that contains four microphones

with 24-bit analog-to-digital converter (ADC) and Kinect-resident signal processing including acoustic echo cancellation and noise suppression. Because there are four microphones, it is possible to record audio from a specific direction, as well as find the location of the sound source and the direction of the audio wave.

- 4) A three-axis accelerometer 2G/4G/8G configured for the 2G range, with a 1° accuracy upper limit. It is possible to use the accelerometer to determine the current orientation of the sensor.

Additionally, the Kinect for Windows sensor is optimized for use with computers and devices running Windows 8.1, 8, 7, and Windows Embedded-based devices [10,11].

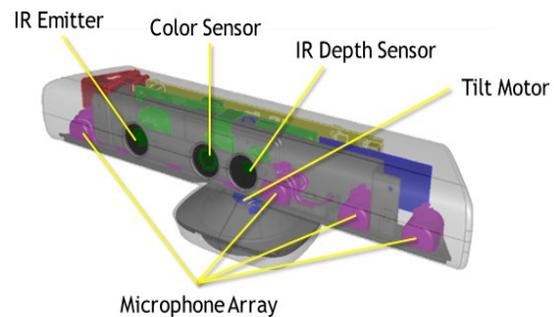


Fig. 2 Kinect sensor components [10]

B. Device field of view

Kinect field of view of the users is determined by the settings of the IR camera, which are set with the DepthRange Enumeration. It is depth data ranges, which determine how close to (or far from) the sensor a person can be and still be in the field of view. Current version of the device allows two possibilities: default and near range. Default range means from 0.8 to 4 meters and near from 0.4 to 3 meters. In both range modes, Kinect can see people with in the natural limitation that is caused by the camera lens. See the Kinect vertical fields of view in default range illustrated in figure 3.

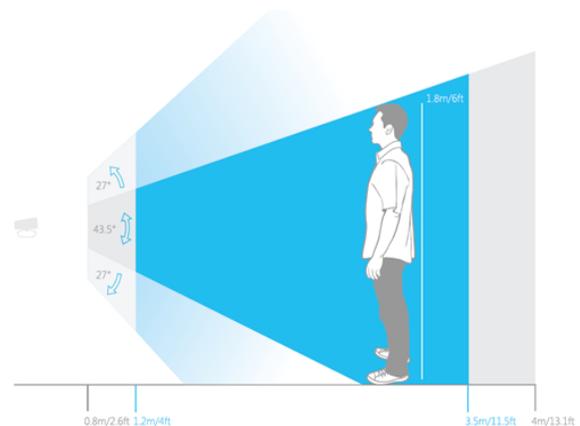


Fig. 3 Vertical field of view in default range [13]

C. Software features

Together with the Kinect device was also released software development kit (SDK). The Kinect for Windows SDK and toolkit contain drivers, tools, APIs, device interfaces, and code samples to simplify development of applications for commercial deployment. The main task of SDK is processes the raw data from the sensor to provide important information for easy implementation in applications.

Fundamental features for this work:

1) Skeleton tracking

Up to six people within its view, including two whole skeletons and follow their actions can track.

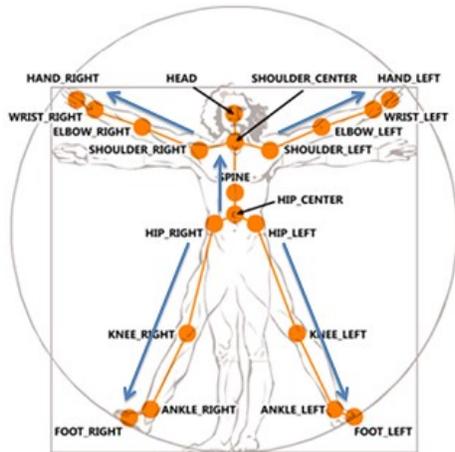


Fig. 4 Collection of joints [10]

2) Full skeleton mode

Kinect for Windows can track skeletons in default full skeleton mode with 20 joints. See fig. 5.

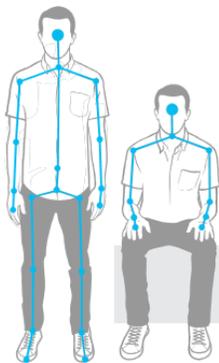


Fig. 5 Default and seated tracking mode [13]

3) Seated mode

Also seated person skeletons can be tracked. The seated mode only tracks the ten upper-body joints (shoulders, elbows, wrists, arms and head). Method of detection is nevertheless different. The default mode detects the user based on the distance of the subject from the background. The seated mode, instead, uses movement to detect the user and distinguish him or her from the background, such

as a couch or chair [11].

For more details and other features see [13].

D. Kinect for Windows SDK

The SDK provides a sophisticated software library and tools to help developers use the rich form of Kinect-based natural input, which senses and reacts to real-world events. The Kinect and the software library interact with application, as shown in Fig 6. The SDK is free, available on the Microsoft web. Currently version 1.8 is available.

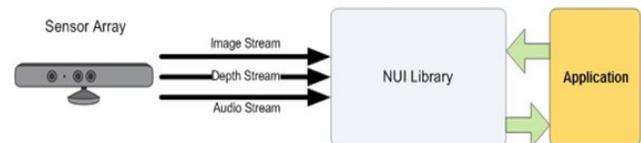


Fig. 6 Hardware and software interaction with an application [10]

Contents of the Kinect for Windows SDK:

- Drivers and technical documentation for implementing Kinect-enabled applications using a Kinect for Windows sensor.
- Reference APIs and documentation for programming in managed and unmanaged code.
- Samples that demonstrate good practices for using a Kinect sensor.
- Example code that breaks down the samples into user tasks.

As a whole, Kinect for Windows architecture includes these components (see also fig. 7):

- 1) Kinect hardware - The hardware components, including the Kinect sensor and the USB hub through which the Kinect sensor is connected to the computer.
- 2) Kinect drivers - The Windows drivers for the Kinect, which are installed as part of the SDK setup process as described in this document. The Kinect drivers support:
 - The Kinect microphone array as a kernel-mode audio device that you can access through the standard audio APIs in Windows.
 - Audio and video streaming controls for streaming audio and video (color, depth, and skeleton).
 - Device enumeration functions that enable an application to use more than one Kinect.
- 3) Audio and Video Components
 - Kinect natural user interface for skeleton tracking, audio, and color and depth imaging
- 4) DirectX Media Object (DMO) for microphone array beamforming and audio source localization.
- 5) Windows 7 standard APIs - The audio, speech, and media APIs in Windows 7, as described in the Windows 7 SDK and the Microsoft Speech SDK. These APIs are also available to desktop applications in Windows 8.

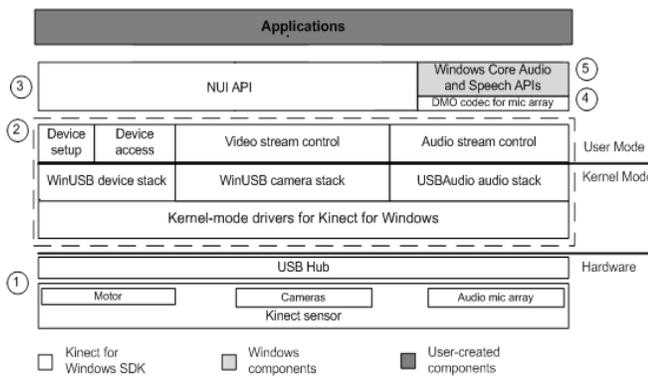


Fig. 7 Kinect for Windows Architecture [10]

IV. JOINT FILTERING

The skeletal tracking joint information can be adjusted (smoothed) across different frames to minimize jittering and stabilize the joint positions over time.

The Kinect for Windows SDK provides a mechanism to smooth the joint positions in a frame. Applications can enable smoothing and Kinect will adjust the position of the joints calculated in that frame according to the desired smoothing behavior.

The smoothing filter used is based on the Holt Double Exponential Smoothing method used for statistical analysis of economic data. This provides smoothing with less latency than other smoothing filter algorithms. The filter can be controlled via five smoothing parameters:

- Smoothing
 - Smoothing parameter. Increasing the smoothing parameter value leads to more highly-smoothed skeleton position values being returned.
 - It is the nature of smoothing that, as the smoothing value is increased, responsiveness to the raw data decreases.
 - Thus, increased smoothing leads to increased latency in the returned skeleton values.
 - Values must be in the range 0 through 1.0. Passing 0 causes the raw data to be returned.
- Correction
 - Correction parameter. Lower values are slower to correct towards the raw data and appear smoother, while higher values will correct toward the raw data more quickly.
 - Values must be in the range 0 through 1.0.
- Prediction
 - The number of frames to predict into the future.
 - Values must be greater than or equal to zero.
 - Values greater than 0.5 will likely lead to overshooting when moving quickly. This effect can be damped by using small values of fMaxDeviationRadius.
- JitterRadius
 - The radius in meters for jitter reduction.
 - Any jitter beyond this radius is clamped to the radius.

- MaxDeviationRadius
 - The maximum radius in meters that filtered positions are allowed to deviate from raw data.
 - Filtered values that would be more than this radius from the raw data are clamped at this distance, in the direction of the filtered value.

A. Code example

The usage of this built-in filter is better to illustrate on examples. Good one is right in MSDN help [14].

The following source code shows the default filter which does smoothing with little latency. Only filters out small jitters. It is good for example for gesture recognition in games.

```
TransformSmoothParameters smoothingParam = new
TransformSmoothParameters();
{
    smoothingParam.Smoothing = 0.5f;
    smoothingParam.Correction = 0.5f;
    smoothingParam.Prediction = 0.5f;
    smoothingParam.JitterRadius = 0.05f;
    smoothingParam.MaxDeviationRadius = 0.04f;
};
```

The second code example shows settings for very smooth filter, but with a lot of latency. It filters out large jitters, which is good for situations where smooth data is absolutely required and latency is not an issue.

```
TransformSmoothParameters smoothingParam = new
TransformSmoothParameters();
{
    smoothingParam.Smoothing = 0.7f;
    smoothingParam.Correction = 0.3f;
    smoothingParam.Prediction = 1.0f;
    smoothingParam.JitterRadius = 1.0f;
    smoothingParam.MaxDeviationRadius = 1.0f;
};
```

The filtering setting in the application is actually simple. It is important to prepare the object TransformSmoothParameters see code samples above and then activate skeleton tracking function with passing this parameter:

```
kinect.SkeletonStream.Enable(smoothingParam);
```

B. Measurement errors

Measurement errors and noise are by-products of almost any system that measures a physical quantity via a sensor. The characteristics of this error are usually described by accuracy and precision of the system, where accuracy is defined as the degree of closeness of measured quantity to its actual value and precision is defined as the degree to which repeated measurements are close to each other. An accurate system does not have any systematic error in measurements and therefore

does not add a systematic bias. A precise system results in measurements close to each other when the measurement is repeated.

Kinect measurement have many parameters that affect the characteristics and level of noise, which include room lighting; a person's body size; the person's distance from the sensor array; the person's pose; location of the sensor array; quantization noise; rounding effects introduced by computations; and so on.

The accuracy and precision concepts are illustrated in following figure. The black X represents the hand location in the real world, and red dots represent a few measurements of hand position by a measurement system.

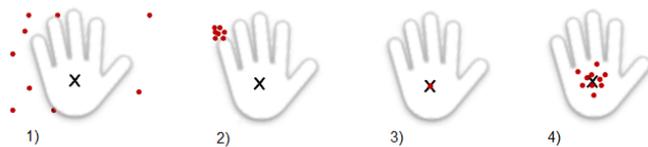


Fig. 8 Kinect for Windows Architecture [15]

Figure 8, part 1) inaccurate and imprecise system generates random-like measurements that are essentially useless in practice. Part 2) inaccurate precise measurement system generates measurements that are close to each other, but have a systematic error or bias. Part 3) is an accurate and precise system, which generates identical measurements that are close to data in the real world. Unfortunately, 100% accurate and precise systems do not exist in the real world, because there will always be some error in practice. Part 4) is also accurate and modestly precise system generates measurements that are close to each other and are not systematically biased with respect to the data in the real world. This is what one should expect in a well-designed system in practice.

V. IMPLEMENTATION

As already mention, the purpose of this work was to use the features of Kinect sensor for monitoring the movement of the human body for objectification of existing otoneurological tests. The first basic test, which has been implemented, is Hautant's test. This test has several descriptions in manual medicine literature [3] however the fundamental conditions are similar.

For Hautant's test, the patient should sit with outstretched arms and closed eyes. The patient task is to keep her/his hand in a fixed position. In view of the fact that her/his eyes are closed, and therefore one of the compensatory senses was lost, this is not, especially for patients with balance disorder, an easy job. The duty of the physician is to track spontaneously movements of patient's hands. The deviation from the beginning position of each hand, the distance (angle) and direction of the deviation are significant data for subsequent diagnostics.

However, this work was not focused on evaluation of

measured results to directly suggest diagnosis, but aim was to prepare a measurement tools.

Imagine a man sitting in a chair with his/her arms outstretched. And you are a person who observes him, and after 30 seconds has to determine how much his arm moved. It is not hard to imagine, it is quite complicated to determine distances in 3D space. The difficulty of this task means in practice that the desired values are mainly estimated. But devices, such as Kinect with IR measurement technology have the potential to be the one to observe and accurately describe the changes.

A. Kinect vision

The figure 9 shows Kinect way of seeing the body joints from skeleton tracking functions linked to video output.

Skeleton data (joints) contains 3D position data for human skeletons for up to two people who are visible in the depth sensor. The position of a skeleton and each of the skeleton joints are stored as (x, y, z) coordinates. Skeleton space coordinates are expressed in meters [14]. The z-axis direct to sensor.

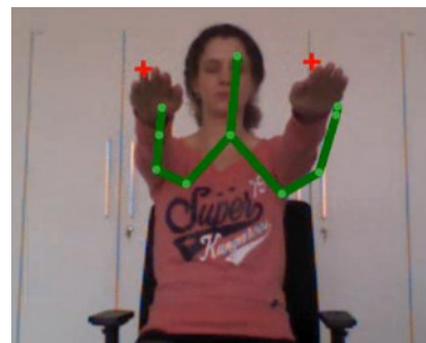


Fig. 9 Kinect vision

B. Software

The software application for measurement and data visualization were prepared. This application was developed in C# language on the .NET Framework 4.0 platform as WPF desktop application. To communicate with the device, the Kinect SDK 1.7 was used, namely the SkeletonStream and ColorStream features.

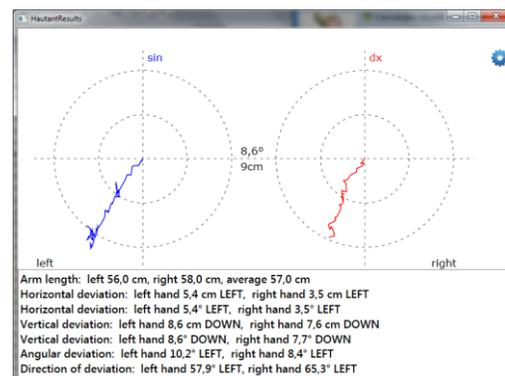


Fig. 10 Evaluated examination results

SkeletonStream

The sensor streams skeleton data using *SkeletonFrame* objects, each of which contains one frame of skeleton data. Each frame of skeleton data contains data for actively and passively tracked skeletons. An application can locate the joints of the tracked persons in space and track their movements over time. Skeleton tracking is designed to recognize users facing the sensor, which is a lack for implementation of some other tests such as the Unterberger stepping test, when monitored person can rotate more than 90 degrees and it may happen that even over 180.

For the programing, the most important class, which is wrapping skeleton stream features of the Kinect device, is the *Skeleton*. It contains skeleton tracking data, which is joint data that is streamed out of a Kinect. To recognize person and visualize its body the *Skeleton* member *Joints* carry fundamental information. It is collection of monitored skeleton elements – joints, where each of it contains data such as the joint type, position, and whether the joint is being tracked.

Joint type ... identifies a portion of the skeleton. Individual joints make up a tracked skeleton. See fig 4.

Position ... position of the joint in 3D, stored in the *SkeletonPoint* object. This is x, y and the z-coordinate of the position in meters.

TrackingState ... is the tracking state of the joint, which indicates the quality of the joint position that was produced by the skeleton stream. Depending on the data available in the depth stream, the skeleton stream may produce joints that are fully tracked, inferred, or not tracked.

ColorStream

The *ColorStream* is used in the current version just for better visualization. In the future, image data would be stored to standard video files to create a comprehensive examination record.

Measurement results have the following visual form – see Fig. 4.

Data filtering

As mentioned earlier the output from the skeleton tracking function is the position of individual points on the human body (joints). See also fig. 4.

Kinect sensor allows getting these positions at a frequency of 30 samples per second.

Not always the joint are determined from the sensor accurately. Each joint has 3D coordinate and state information describing the quality of the recognition. There are three levels: tracked, inferred, not tracked. See previous paragraph. Skeleton tracking functions also allow using predefined filter and smoothing algorithms to minimize jittering and stabilize the joint positions over time [10]. This function has also been used in the developed application. Experiments have shown that good results are achieved by these filter settings:

```
TransformSmoothParameters smoothingParam = new
TransformSmoothParameters();
{
    smoothingParam.Correction = 0.1f;
    smoothingParam.JitterRadius = 0.005f;
    smoothingParam.MaxDeviationRadius = 0.004f;
    smoothingParam.Prediction = 0.1f;
    smoothingParam.Smoothing = 0.9f;
};
```

However algorithms are defined universally and for specific tasks such as Hautant's test was appropriate to supplement also own algorithm that takes into account the specifics of this test. For the Hautant's test, only the hands position in time is tracked and these changes are relatively slow.

The algorithm for subsequent smoothing, focusing on short-term peak (abrupt changes) were implemented. The algorithm consists of two phases:

- elimination of uncertain points
- gradient filtering

Elimination of uncertain points

Experimental measurements showed that for the further evaluation is suitable to use only the skeleton joint with tracked status. All joints with inferred status were excluded from the evaluation algorithm. They are also excluded from the visualization. To evaluate Hautant's test and smooth visualization of measurement is fully sufficient to have several samples per second and thus the output sample rate of Kinect sensor - 30 samples per second, allow this brevity.

Gradient filtering

Second phase of the measured data adjustments consists in removing the short-term peaks. The gradient filter was implemented for this purpose. The maximum change of 25 mm/s was experimentally determined and for the first presented version used. Value was named *MAG* (maximal allowed gradient).

The algorithm for the determination of *i* joint works in following way (two previous and one following values are evaluated, labeled i_{-2} , i_{-1} and i_{+1}):

- 1) If the difference of sample $|i - i_{-1}|$ is smaller than *MAG* the measurement value *i* is considered as correct.
- 2) If not, the auxiliary values *A* and *B* are calculated. *A* arises from linear stretching (extrapolation) of value i_{-2} and i_{-1} . *B* is created by linear interpolation of i_{-1} and i_{+1} .
- 3) If any of the auxiliary values *A* or *B* does not satisfy the *MAG* rule, it is corrected to the previous value of i_{-1} +/- maximal gradient. (+/- sign depends on the direction of increase or decrease)
- 4) The resulting value *i* is chosen from *A* or *B* by the rule:
 - If the next sample i_{+1} (ignoring value of *i*) is considered as correct (*MAG* rule between points i_{-1} and i_{+1} is met) *B* is assigned to *i*.
 - If the previous rule does not apply, and therefore value i_{+1} as well as *i* is considered improperly

tracked, A is used for further decisions. However, if the measured value i is greater than A , the MAG is added to A . Thus, there is a shift towards a measured value. Conversely, if the measured value is less than or equal to A , the MAG is subtracted from A . Finally A is assigned to i . The MAG between determined i and i_1 is respected and values are adjusted, if necessary.

The following figure shows the resulting (filtered) values in the context of the measured data (raw).

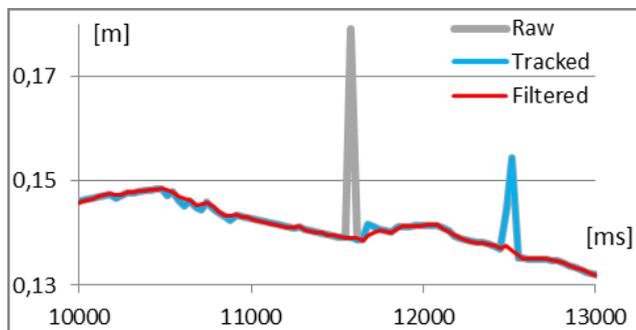


Fig. 11 Filtered results

Length of arm

Proposed implementation of Hautant's test also implements determination of the length of patient's arms. This value can be easily measured by conventional means, but to simplify the whole process of examination, this information is also obtained from the Kinect data.

Length of the arm is calculated by simplified algorithm when the length is determined as the distance from the shoulder joint to the hand, see (1).

$$Arm = \sqrt{\begin{matrix} (Shoulder.X - Hand.X)^2 + \\ (Shoulder.Y - Hand.Y)^2 + \\ (Shoulder.Z - Hand.Z)^2 \end{matrix}} \quad (1)$$

where: Shoulder and Hand are joints positions with X, Y, Z coordinates in meters.

Evaluation of the test

The basis of the evaluation of Hautant's test is determination of horizontal and vertical deviation from the starting point of the measurement. These values are both expressed in centimeters, but also as an angle (using the length of the arm), see (2). Another output of the proposed software is information about the total angular deviation and direction of the deviation.

The results are also graphically visualized see fig. 10. Numerical results are shown in the lower part of the window – fig. 10.

The formula for expressing the angular deviation aD :

$$aD = \tan^{-1} \frac{hD}{\sqrt{Arm^2 - \frac{C^2}{4}}} \quad (2)$$

where: hD is horizontal (or vertical) deviation,
 C is circle chord ($C = 2 * hD$),
 Arm is the length of the arm.

The fig. 12. and 13. show other useful view of measured data. Fig. 12 shows the speed of change in the vertical direction. Horizontal deviation is shown on fig. 13. The figures for example show that deviation of left hand was slightly larger.

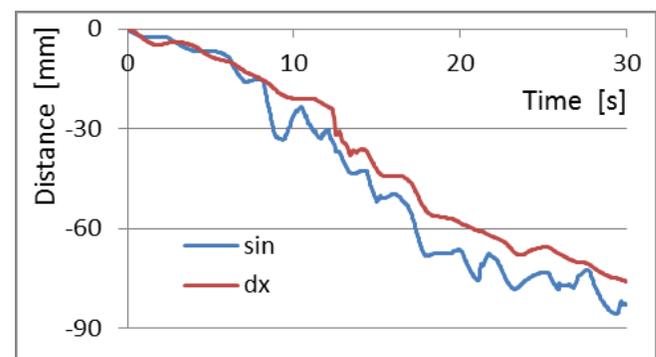


Fig. 12 Vertical deviation

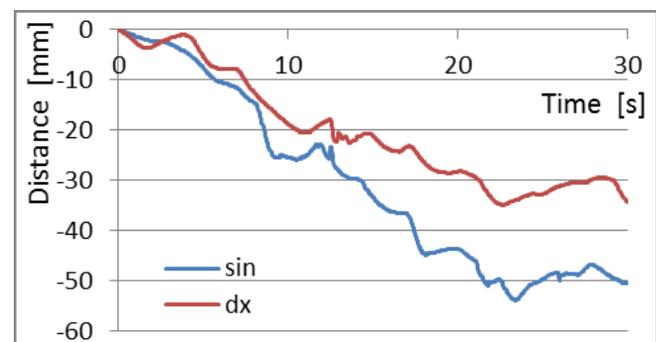


Fig. 13 Horizontal deviation

VI. CONCLUSION

The present article shows the initial part of the project focused on the use of gaming devices in medicine. Kinect, originally created for the Xbox game console and later also introduced for Microsoft Windows operating system has potential for use in the evaluation of classical tests of the balance in medicine. Such a test may be Hautant's positional test, which was also implemented and presented in this article. The measured data will need to be further verified and form of its presentation must also be consulted in detail with specialized physicians. Future work should, together with improvements of implemented Hautant's test focus on implementation of other tests such as Unterberger (Fukuda) stepping test.

ACKNOWLEDGMENT

The work was supported by the European Regional Development Fund under the Project CEBIA-Tech No. CZ.1.05/2.1.00/03.0089.

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