A NEW MODEL OF ULTRA WIDEBAND SENSORS BASED INTERACTIVE SYSTEM

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Abstract: Camera Based Interactive Systems have found their application in various fields of human activity, such as education, industry, entertainment, healthcare, public order, etc. It could be noted that in the characteristics of such a system, certain shortcomings or weaknesses could be highlighted. To reduce these weaknesses, a new model, based on digital communication devices in the wideband radio frequency spectrum is proposed. The technology used is ultra-wideband based, through the construction of a wireless sensor network. This paper proposes a model of an ultra-wideband wireless sensor-based interactive system that implements the spatial orientation approach and the precise local positioning approach. A synthesis of the new model comprises four phases.

Key words: UWB, wireless, interactive, positioning, system.

1. INTRODUCTION

The establishment of an interactive model based on a feedback camera (Camera Based Interactive System, CBIS) leads to its wide application in various fields of human activity. In a number of fields such as education, industry, entertainment, healthcare, public order, etc. are built or use systems of this class. Looking at the characteristics of such a system, certain shortcomings or weaknesses could be highlighted. In the analysis of this type of interactive systems based on a feedback camera, these shortcomings can be classified into two directions:

- Technology-oriented;
- Project-oriented.

The following technological shortcomings can be summarized in the first direction:

- Use of additional complex hardware equipment (camera);
- Coordination of the camera and the program algorithm requirement of the interactive system;
- Using an optical transmitter;
- Direct visibility requirement;
- Calibration process requirement;
- Higher power consumption.

The following design-related deficiencies can be attributed to the second direction:

- Lower spatial coverage;
- More difficult system scaling process;
- Lower degree of Inter-System integration;
- Higher implementation costs.

Based on the above-mentioned shortcomings of the existing feedback camera-based interactive systems, the following conclusions can be summarized:

1. When synthesizing new models of such CBIS, certain technological approaches should be considered, by means of architectural organization of the network infrastructure through the usage of Internet of Things, Cloud Computing, Industry 4.0, Wireless Sensor Networks, Cyber Physical Systems [1, 2];
2. Intersystem integration in existing CBIS is highly limited due to the presence of technological specifications of certain components (camera, optical emitter, etc.), which lead to the creation of complex hardware and software interfaces;
3. Existing CBIS have certain limitations in compatibility with modern approaches such as generally accessible environment with opportunities for remote use of information resources in connected local segments [2].

As main objective of the present paper, a new model of a specific interactive system is presented, which could replace in certain cases the models of the existing CBIS. A second objective is to overcome the above mentioned weaknesses and expand the functional characteristics of an such interactive system.

The proposed new model originated by the digital communication devices in the wideband radio frequency spectrum. The technology used is ultra-wideband (UWB) [6, 7] based, by building a wireless sensor network. In such technology a real-time indoor location tracking system [8, 9] is applied along with keeping accuracy and reliability [10, 11]. In the proposed new model of UWB wireless sensor-based interactive system (UWBWSBIS), the spatial orientation approach and the precise local positioning approach are applied, occupying an increasingly wide place in positioning systems in various applications.

2. THEORETICAL BASE

2.1 Working principles

In the present work, a synthesis of new model of the ultra-wideband sensors base interactive system is proposed as follow. For the goal of synthesis, certain steps should be taken. As a first phase, certain principles should be accepted:

- Local positioning with a high degree of accuracy, based on ultra-wideband sensor radio networks;
- Projection of a point from the spatial orientation of the mobile interactive user device (MIUD) by means of geometric algorithms;
- Use of passive RFID devices for tags;
- Interaction based on coded pulse sequences generated by MIUD;
- Implement assignment reversibility for MPT and RDT tags.

It should be noted that UWB technology for positioning an object reaches accuracy ε=10 mm [3, 4, 5], which is assumed to be the acceptable value of positioning error in the current model, and which error would not have a significant impact when working with a synthesized system by means of the presented model.

2.2 Domain of model restraints

As a second phase in this process, a domain of model restraints definitions needs to be formed. The restraints outline technical aspects of specifications that must be applied while such system is developed. To achieve effectiveness, it is obligatory all restraints to be satisfied.

Following such an approach in the first phase of the model synthesizing, a set of restraints is adopted:

a). A radio frequency device with radio frequency detection (reading) functionality of a radio frequency sensor is defined as a “marker”;
b). A radio frequency sensor that is detected by a marker is defined as a “tag”.
c). Three markers - M_initial, M_width and M_height are established;
d). Two tags with interchangeable assignments A_tag and B_tag are established;
e). A constant distance between A_tag and B_tag is established;
f). A “Main Position Tag” (MPT) assignment is established;
g). A “Reference Direction Tag” (RDT) assignment is established;
h). A three-dimensional space I is established;
i). An interactive plane is established;
j). The vectors of the abscissa and ordinate axes of the interactive plane are collinear and point in identical directions to their corresponding vectors of the three-dimensional space I;
k). A zero displacement of the interactive plane along the z-axis of the I-space is established;
l). Effective Interactive Work Area (EIWA) is established;
m). The abscissa and ordinate axis vectors of EIWA are collinear and point in identical directions to their corresponding axis vectors in the interactive plane;
n). The origin of the EIWA Cartesian coordinate system is established referred to M_initial (x=0,y=0);
o). Zero displacement of EIWA along the z-axis of the three-dimensional space I is established;
p). Markers M_initial and M_width lie on the abscissa axis of EIWA;
q). Markers M_initial and M_height lie on the ordinate axis of EIWA;
r). Zero offset of the M_initial, M_width, and M_height markers along the EIWA z-axis is established;
s). A positioning area is established with a width, specified by M_width and a height, specified by M_height;
t). EIWA is purposed as a screen for the projection subsystem;
u). A user’s horizontal movement area (UMA) is established with fixed dimensions UMA_width and UMA_depth whose start matches M_initial.

3. SYNTHESIZING A MODEL

3.1. Spatial model definition

The third phase of the model synthesizing includes graphically representation of the above adopted restraints in details as pointed in Fig.1.

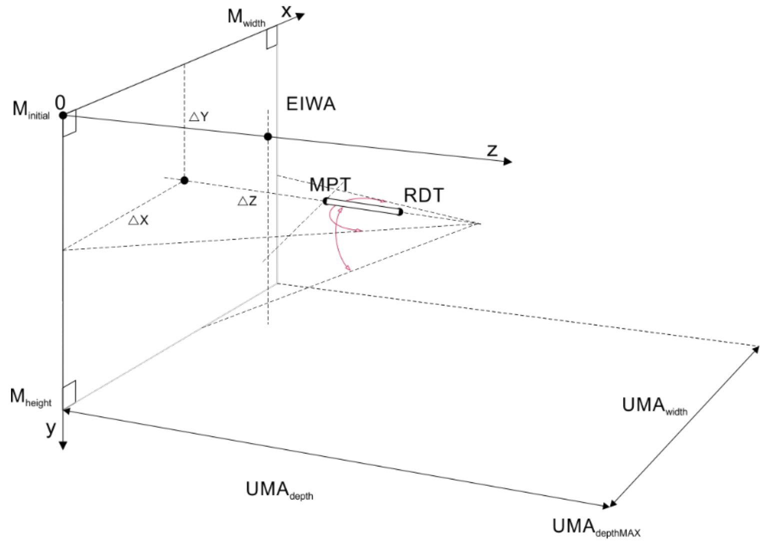

Figure 1. Geometrical representation of the accepted placements in the model.

Figures 2, 3 and 4 present the three aspects of the MIUD design approach in the three planes XY, XZ and ZY. In this approach, the main argument is the six degrees of freedom (DOF) of the MIUD - three translations along X,Y,Z and three rotations (relative to the RDT point) along the axes Z (fig.2), Y (fig.3) and X (fig.4).

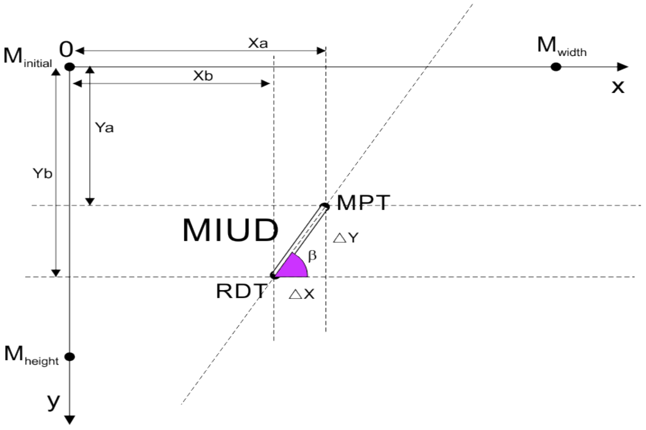

Figure 2. An approach projecting relative to the XY plane by spatial position.

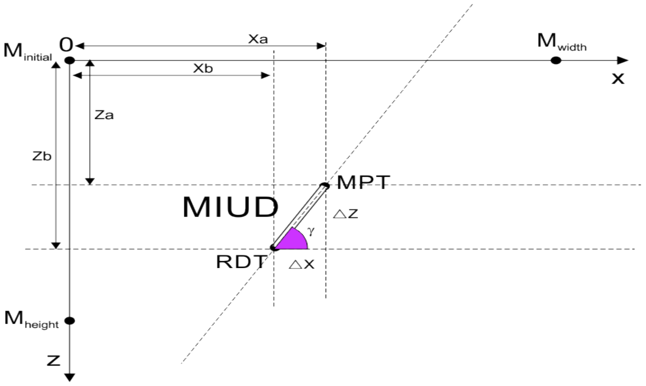

Figure 3. An approach projecting relative to the XZ plane by spatial position.

The choice of local positioning principle in UWB sensor networks is based on the following advantages:

- wider working range;
- better range resolution for accurate localization;
- lower sensitivity to interference;
- larger possibilities for multiple access.

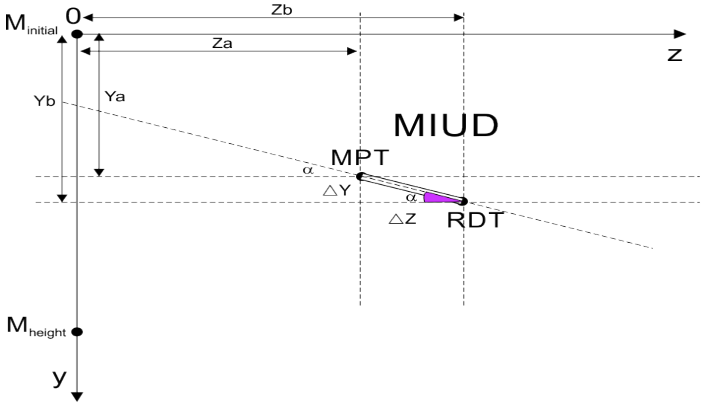

Figure 4. An approach projecting relative to the ZY plane by spatial position.

The rotation angles of the MIUD in three-dimensional space define a spatial domain constraining the spatial orientation of the MIUD.

3.2. Model formalization

In the synthesis of the new model, as a logical step in this fourth phase, a formalization will be carried out. Let the following arguments be given, presented below:

$$I_{xyz} = \{x : R, y: R, z: R\} \tag{1}$$

$$MPT_{xyz} \in I_{xyz} \tag{2}$$

$$RDT_{xyz} \in I_{xyz} \tag{3}$$

$$M_{initialXYZ} \in I_{xyz} \tag{4}$$

$$M_{widthXYZ} \in I_{xyz} \tag{5}$$

$$M_{heightXYZ} \in I_{xyz} \tag{6}$$

$$UMA_{widthXYZ} \in I_{xyz} \tag{7}$$

$$UMA_{depthXYZ} \in I_{xyz} \tag{8}$$

Where

I_{xyz} is the set of coordinates of points in the three-dimensional space I, in which the coordinates are elements of the set of real numbers R. MPT_{xyz}, RDT_{xyz} are the sets of the coordinates of points in the tridimensional space I, of tags MPT and RDT, respectively, and $M_{initialXYZ}$, $M_{widthXYZ}$, $M_{heightXYZ}$ are sets of the coordinate points in the three-dimensional space I, of markers $M_{initial}$, M_{width} and M_{height}, respectively. A, the user's movement is constrained by $UMA_{widthXYZ}$ and $UMA_{depthXYZ}$, representing sets of his positional coordinates in the UMA.

With the arguments thus defined, the following formalization is made:

$$x' = M_{initialXYZ}(x|\ x = 0) \tag{9}$$

$$y' = M_{initialXYZ}(y|\ y = 0) \tag{10}$$

$$d' = UMA_{depthXYZ}(z|\ z \leq UMA_{depthMAX}\ ) \tag{11}$$

The following lines are definition of certain limitations applicable to spatial translations:

$$\begin{gathered}
(\forall MPT_{xyz}\ (z\,|\,z > 0\ \land (z\ \in (I_{xyz} \cup MPT_{xyz}\ ))))\\
\land(\forall RDT_{xyz}\ (z\,|\,z < d' \land (z\ \in (I_{xyz} \cup RDT_{xyz}\ ))))\\
\land(\forall RDT_{xyz}\ (z\,|\,z > 0\ \ \land(z\ \in (I_{xyz} \cup RDT_{xyz}\ ))\land(RDT_{xyz}(z) > MPT_{xyz}(z))))\\
\land(\forall RDT_{xyz}\ (z) \leq d')\\
\land(\forall MPT_{xyz}\ (x\,|\,x \geq x' \land(x \in (I_{xyz} \cup MPT_{xyz}\ ))\\
\land(x < M_{widthXYZ}\ (x \in (I_{xyz} \cup MPT_{xyz}\ )))))\\
\land(\forall MPT_{xyz}\ (y\,|\,y \geq y'\ \land(y \in (I_{xyz} \cup MPT_{xyz}\ ))\\
\land(y < M_{heightXYZ}\ (y \in (I_{xyz} \cup\ MPT_{xyz}\ ))))) \rightarrow P_{translation}\ > 0)
\end{gathered} \tag{12}$$

The above defines an interval of values of the spatial coordinates x, y, z of the tags with assigned MPTs and RDTs integrated into the MIUD, in which translation of the MIUD in the system is possible, i.e. there is a probability of effective translation $P_{translation}$.

3.3. Program algorithm

Next phase demands MPT and RDT assignments to have a programmatic dimension. The synthesis of the model takes an approach using the following two-step algorithm composed of *assignment* (13) and *operation* (18).

$$\begin{gathered}
if\left(A_{tag}(z) < B_{tag}(z)\right) then\\
\left\{MPT = A_{tag}\ and\ RDT = B_{tag}\right\} else\\
\{MPT = B_{tag}\ and\ RDT = A_{tag}\}
\end{gathered} \tag{13}$$

To proceed with the presentation of the second part of the algorithm, it is necessary to define certain DOF constraints of the MIUD. These constraints are successively presented in Fig. 5 and 6. In Fig. 5 case 1 is considered, in which $MPT_{xyz}(y) <$

$RDT_{xyz}(y)$ is valid for a tag with assignment MPT. In Fig.6, case 2 is considered, in which $MPT_{xyz}(y) > RDT_{xyz}(y)$ is valid for a tag with MPT assignment.

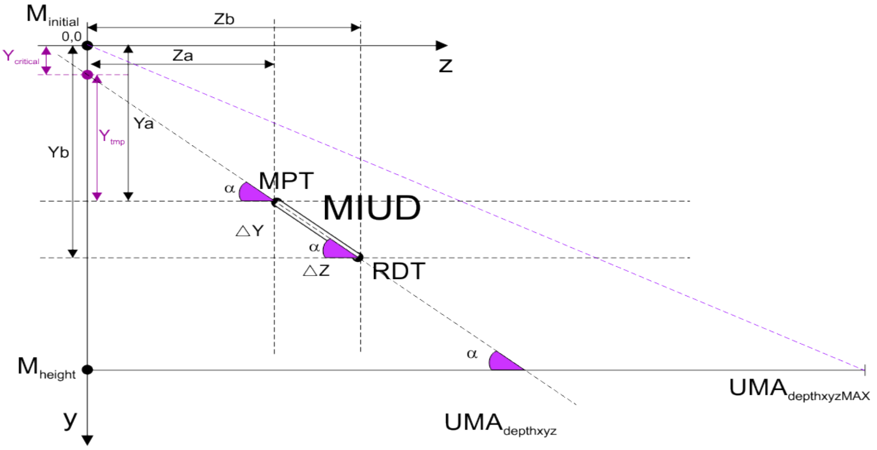

Figure 5. Geometric representation of DOF constraints for MIUD-case 1.

Case 3 is also allowed to occur, where $MPT_{xyz}(y) = RDT_{xyz}(y)$ is valid. In this case 3 angle $\alpha = 0^0$, which determines $Y_{tmp} = 0$ and following the mathematical logic formulated in (19) then $Y_{critical} = Y_a$.

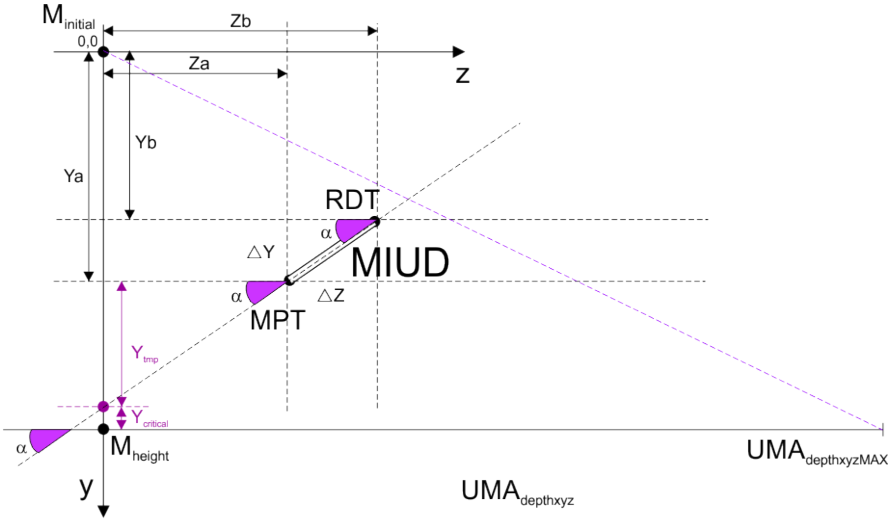

Figure 6. Geometric representation of DOF constraints for MIUD – case 2.

It should be noted that due to the complex nature of the considered mathematical apparatus used to represent all aspects in this algorithm and in view of the given limitations of the volume of this publication, the basic mathematical apparatus is presented only for the ZY plane, and for the XY and XZ planes it will be valid analogical mathematical logic.

Looking at the geometric representation of Fig.5, and determining the below

$$tg(\alpha) = \frac{\Delta y}{\Delta z}, \tag{14}$$

the following setups can be defined:

$$Y_{tmp} = Z_a tg(\alpha) \tag{15}$$

$$Y_{critical} = Y_a - Y_{tmp} \tag{16}$$

For case 2, presented in Fig. 6, (15) is valid. Here the value of $M_{heightXYZ}(y)$ is used to determine $Y_{critical}$.

$$Y_{critical} = M_{heightXYZ}(y) - Y_a + Y_{tmp} \tag{17}$$

Formulations (16,17) determine the critical value of the MIUD rotation through the RDT, relative to the X-axis, at which user interaction in the system is possible. Relying on the geometric concept in the figures presented above, the second step of the algorithm is constructed by means of pseudocode shown below (18).

```
Set $M_{initialXYZ}$ = 0,0,0
Set $M_{widthXYZ}$
Set $M_{heightXYZ}$
Set $\mathrm{UMA_{depthxyzMAX}}$
Set $\mathrm{P_{translation}}$ = 0
Set $\mathrm{P_{interaction}}$ = 0
Add event listener for MIUD tracking
MIUD tracking event listener updates $\mathrm{P_{translation}}$ and $\mathrm{P_{interaction}}$
If ($\mathrm{P_{translation}} > 0$) then
  If ($P_{interaction} > 0$) then
      If MIUD button is Pressed then
          doEventOnSimulationContext
      Endif
  Endif
Endif                                                        (18)
```

3.4. Architecture organization

Following the above, the UWBWSBIS architecture shown in Fig.7 is presented. The proposed architecture of the ultra-wideband wireless sensors base interactive system does presents four main subsystems:

- Interactive simulation server;
- UWB positioning system;
- Mobile interactive user device;
- Projector system.

Mainly interactive simulation server is intended for interactive scenarios generation through AVISS, database managing, user interactions managing via dedicated interface (IM), capturing projection of a point of the MIUD on EIWA, events results storage (MS). Projector system has its common functionality to exposure the video stream of generated scenarios by AVISS on the EIWA. The UWBPS is used for real-time tracking and positioning of the MIUD. The MIUD itself is used for projection of a point on EIWA from the spatial orientation, and to acts as interaction element, based on coded pulse sequences.

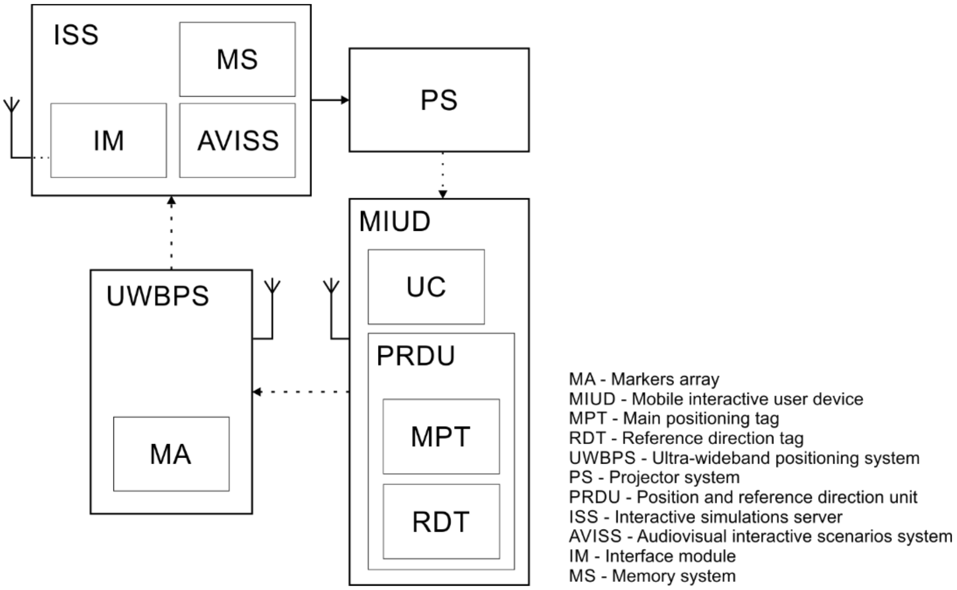

Figure 7.An architecture of UWBWSBIS.

4. CONCLUSION

The presented new model could serve for the design and development of a prototype for a UWB wireless sensor-based interactive system based on spatial orientation through precise local positioning. The main contribution and scientific novelty of the discussed new model could be summarized as follow – *no need of usage of additional complex hardware equipment (camera); no need of coordination of the camera and the program algorithm; no need of usage an optical transmitter; no need of direct visibility requirement; no need of calibration process; low power consumption*; *opportunity of usage of technologies as IoT, Cloud computing; system scalability opportunity, integration opportunity.* As benefit of that new model could be pointed follow - *less hardware equipment, more flexible system design and support*.

The solution presented above does not cover the architecture and principles of the user device for positioning control, the system for audio-visual interactive scenarios and the architecture of the server for interactive simulations, which will be the subject of subsequent publications. The coded pulse sequences of the MIUD subsystem will regarded in future work as well.

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