A Novel Approach to Time-Space-Direction Algebra for Collaborative Work in Ubiquitous Environment

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Abstract

In this paper, we discuss on a novel approach to time-space-direction algebra for collaborative work in ubiquitous environment. A time-space-direction algebra is a mathematical form and a system describing physical and electronic objects with temporal, spatial, and directional features in ubiquitous environment. It enables us to describe any behaviors for physical and electronic objects in ubiquitous environment. The main features of our approach are as follows. The first one is the description capability and reduction of computational complexity. The second is that by including the directions of objects in metadata precision for semantics extracted metadata is improved. We also show several applications of our algebra for collaborative work. In this paper we describe the feasibility of our algebra by several experimental results.

1. Introduction

In the field of ubiquitous computing and context awareness computing, various sensor network and its applications[2, 5, 6, 8, 14] are designed and implemented. We also have several proposals for supporting ubiquitous sensor networks[7, 12]. These sensor networks include such as GPS, RFID, infra-red tags. etc. These sensors produce data sequences which include time and space information.

Another time and space information extraction is video analysis. Video analysis enables us to extract metadata sequence for target objects, which include time and space of target moving objects (e.g. [10]).

Integration of temporal and spatial features with normalizations for above information (time and space information) improves descriptive power on all behaviors of objects.

The definition of sequences for these normalized metadata enables us to describe and operate complex behaviors of objects in ubiquitous environment.

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Even time and space information is normalized, there is certain semantic gap between time space sequence and human and object actual moving. For example, when a human stands close to another human, sometimes it is hard to tell, the human is talking to the another only from the information of detected location. The detection of directions of human and object will make much smaller the gap between physical situation and semantics.

In this paper, we discuss on a novel approach to time-space-direction algebra for collaborative work in ubiquitous environment. A time-space-direction algebra is a mathematical form and a system describing physical and electronic objects with temporal, spatial, and directional features. It enables us to describe any behaviors for physical and electronic objects.

Temporal relationships[1] and spatial relationships[4] among two objects have been proposed. By adding direction and set-operators, we define unified description form as time-space-direction algebra.

The main features of our approach are as follows. The first one is the description capability and reduction of computational complexity. The second is that by including the directions of objects in metadata, precision for semantics extracted metadata is improved. We show several applications of our algebra for collaborative work.

In this paper we describe the feasibility of our algebra by several experimental results for applications on intra-organization collaborative work.

2. Time-Space-Direction Algebra

In this section we describe a basic model of Time-Space-Direction Algebra.

2.1. Data Structure

Firstly, we define basic elements and our data structure.

Every single physical and electronic object has following basic elements:

- ID (an identifier of an object)
- Point1 (x1,y1,z1: a spatial position an object)

- Point2 (x2,y2,z2: a direction of an object is defined by a vector from Point1 to Point2)
- Timestamp (date and time)

Every single object is identified by ID. A temporal feature of an object is described as Timestamp. A spatial feature is expressed by Point1. A direction of an object is described by the direction from Point1 to Point2. By Point1 and Point2, only the direction of the object is described (distances between the two points have no meaning). Normalization of the direction is required according to the degree of precision on directions for applications of this model.

We define data structure "tuple" for describing a snapshot of an object as follows:

$(ID, x1, y1, z1, x2, y2, z2, t)$

We define data structure "sequence" for describing behaviors of objects with temporal, spatial, and directional features as a sequence:

$(ID, x1_1, y1_1, z1_1, x2_1, y2_1, z2_1, t_1)$,
$(ID, x1_2, y1_2, z1_2, x2_2, y2_2, z2_2, t_2)$,
...,
$(ID, x1_n, y1_n, z1_n, x2_n, y2_n, z2_n, t_n)$

This data structure "sequence" is ordered sets of coordinates $(x1_i, y1_i, z1_i)$ and relative direction to $(x2_i, y2_i, z2_i)$ of ID at the time t_n.

2.2. Operators

Now we define operators for Time-Space-Direction Algebra. We classify operators as follows:

- Temporal Comparison-Bi-Operators
- Spatial Comparison-Bi-Operators
- Arithmetic-Bi-Operators
- Uni-Operators
- Matching-Operators

Research papers [1] and [4] present temporal and spatial relationships among two objects.

By adding direction and set-operators, we define unified description form as time-space-direction algebra. We have designed arithmetic-bi-operators, uni-operators, matching-operators.

2.2.1. Temporal Comparison-Bi-Operators We use temporal relationship[1] for temporal compare-bi-operators (operators for comparing two objects) for temporal aspects.

- $before_t$: returns true when the one sequence occurs before the other sequence.
- $after_t$: returns true when the one sequence occurs after the other sequence.
- $during_t$: returns true when the one sequence occurs during the other sequence.
- $contains_t$: returns true when the temporal range of the one sequence contains the range of the other sequence.
- $overlaps_t$: returns true when the temporal range of the one sequence overlaps the range of the other sequence.
- $overlappedby_t$: returns true when the temporal range of the one sequence is overlapped by the range of the other sequence.
- $meets_t$: returns true when the temporal range of the one sequence meets the range of the other sequence (the end point of the one sequence equals the start point of the range of the other one).
- $metby_t$: returns true when the temporal range of the one sequence is met by the range of the other sequence (the start point of the one sequence equals the end point of the range of the other one).
- $starts_t$: returns true when the one sequence starts with the other sequence.
- $startedby_t$: returns true when the one sequence is started by the other sequence.
- $finishes_t$: returns true when the one sequence finishes with the other sequence.
- $finishedby_t$: returns true when the one sequence is finished by the other sequence.
- $equals_t$: returns true when the one sequence equals the other sequence.

These operators satisfy a distributive property and a associative property (basic mathematical properties or rules). They do not satisfy a commutative property. Only the operator $equals_t$ satisfy commutative property.

2.2.2. Spatial Comparison-Bi-Operators We use spatial relationship[4] for spatial compare-bi-operators (operators for comparing two objects) for spatial aspects.

- $disjoint_s$: returns true when the one sequence and the other sequence are disjoint.
- $contains_s$: returns true when the one sequence contains completely the other sequence.
- $inside_s$: returns true when the one sequence is inside of the other sequence.
- $equal_s$: returns true when the one sequence equals the other sequence.
- $meets_s$: returns true when the one sequence touches to the other sequence. (the trajectory of the one sequence touches to the other one of the other sequence)
- $covers_s$: returns true when the one sequence covers and touches the other sequence.
- $coveredby_s$: returns true when the one sequence is covered and touched by the other sequence.
- $overlaps_s$: returns true when the one sequence overlaps the other sequence.

2.2.3. Arithmetic-Bi-Operators Operators above (temporal comparison-bi-operators and spatial comparison-bi-operators) are based on research papers [1] and [4] which present temporal and spatial relationships among two objects.

By adding direction and set-operators, we define unified description form as time-space-direction algebra. Now we have designed arithmetic-bi-operators, uni-operators, matching-operators.

In this section, we define arithmetic-bi-operators for sequences of objects as follows.

- add_t (or_t) : outputs one sequence added temporally to the other sequence. This is corresponding to logical OR operator.
- $difference_t$: outputs temporal difference between the one sequence and the other sequence.
- $mult_t$ (and_t) : outputs temporally equal part of one sequence and the other sequence. This is corresponding to logical AND operator.
- $division_t$: outputs temporal corresponding part of the one sequence by the other sequence, like division in relational algebra[3].

- add_s (or_s) : outputs the one sequence of the one sequence added spatially to the other sequence. (outputs the sequence generated from the one area of the one sequence added spatially to the other area of the other sequence)
- $difference_s$: outputs spatial difference between the one sequence and the other sequence.
- $mult_s$ (and_s) : outputs spatially equal part of one sequence and the other sequence.
- $division_s$: outputs spatial corresponding part of the one sequence by the other sequence.

These operators satisfy a distributive property and a associative property. The operators 'add_t,' 'add_s,' '$mult_t$' and '$mult_s$' satisfy a commutative property. The operators '$difference_t$,' '$difference_s$,' '$division_t$' and '$division_s$' do not satisfy commutative property.

2.2.4. Uni-Operators We define uni-operators for sequences of objects as follows.

- not_t : returns all other objects except the object temporally.
- not_s : returns all other objects except the object spatially.
- not : returns all objects except the object.
- $reverse$: returns the objects (sequence) in reverse order.

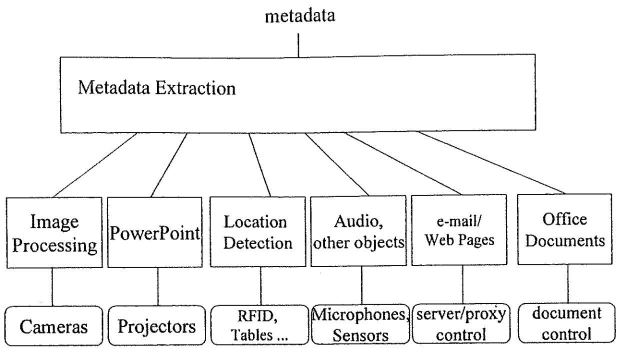

Figure 1. An overview of environment for our algebra

2.2.5. Matching Operators We define matching-operators as follows.

- $strict\_match$: returns true when the one sequence matches strictly to the other sequence
- $match\_with\_temporal\_quantization$: returns true when the one sequence matches to the other sequence with temporal quantization (matches with temporal ambiguity)
- $match\_with\_spatial\_quantization$: returns true when the one sequence matches to the other sequence with spatial quantization (matches with spatial ambiguity)
- $match\_with\_ID\_quantization$: returns true when the one sequence matches to the other sequence with ID quantization (matches from the viewpoint of only temporal, spatial and directional features)

3. An Application for Automatic Metadata Extraction in Ubiquitous Meeting Environment

In this section, we discuss on an application for automatic metadata extraction in ubiquitous meeting environment.

As ubiquitous environment, we use experimental environment that we can obtain temporal, spatial and directional values, by multiple sensor network as shown Figure 1.

We have already proposed automatic and immediate metadata extraction method by heterogeneous sensors for meeting video streams[18]. The main feature of our model (described in Section 2) in comparison with previous work[18] is following two points. The first one is the description capability and reduction of computational complexity. The second is that by including the directions of objects in metadata, precision for semantics extracted metadata is improved. We show several applications of our algebra for collaborative work.

We set up ubiquitous environment (Figure 3) for this application. We also implemented automatic metadata extraction system by our algebra (Section 2) shown in Figure 2.

Locations of objects (people, a whiteboard, a chair) are detected by location sensors[9]. A direction of an object is captured by two location sensors for each object.

The process of automatic metadata extraction consists following four steps[18]:

- Step-1: Sensor Identification
- Step-2: Sensor Data with Time Stamping
- Step-3: Generation of Metadata
- Step-4: Storage for Metadata

Our algebra is applied to Step-3. In this step, sensor data and the sensor-metadata database (given semantics for combinations of heterogeneous sensors) is compared. Metadata is output by metadata manager in Figure 2 when sensor data and any entries of the sensor-metadata database are matched.

Sensor data with synchronization by time stamping and the sensor-metadata database (given semantics for combinations of heterogeneous sensors, Figure 2) is compared. And metadata is output when sensor data and any entries of the sensor-metadata database are matched.

3.1. Conflict Resolution

When we build the sensor-metadata database (Figure 2), there may exist conflict among sets for combinations of sensors data and corresponding metadata. We include conflict resolution engine for this problem. We designed following conflict resolutions.

- temporal conflict resolutions (when more than two entries with same ID, temporal features, and inconsistent metadata in the sensor-metadata database (Figure 2), the conflict resolution engine (Figure 2) detects and notifies them.
- spatial conflict resolutions (when more than two entries with same ID, spatial features, and inconsistent metadata in the sensor-metadata database, the conflict resolution engine detects and notifies them.

4. Experiment

4.1. Overview

To clarify the feasibility of our Time-Space-Direction Algebra, we performed experiments for the application of metadata extraction on meetings in ubiquitous environment.

4.2. Experimental Environment

We have many proposals for sensor network in ubiquitous environment [9, 11, 13] for collaborative work in ubiquitous environment.

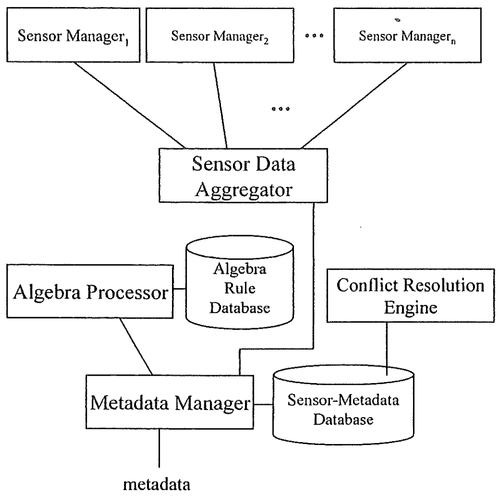

Figure 2. System Overview for an Application of Time-Space-Direction Algebra for Metadata Extraction in Ubiquitous Environment

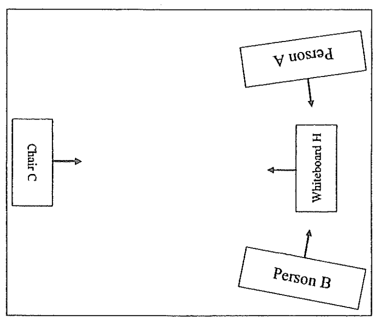

Figure 3. Environment for an Application of Time-Space-Direction Algebra for Metadata Extraction in Ubiquitous Environment

We have built collaborative work room[11] (Figure 3), and automatic metadata extraction system by our algebra (Section 2) shown in Figure 2.

4.3. Experiment 1: Feasibility of Arithmetic Operators

We consider the situation that two people A and B are approaching to the whiteboard H.

We can describe various conditions in the situation by using our algebra.

We describe whiteboard H (stable), A's approach to H, and B's approach to H as follows:

- $seq100 = (H,\ 2.0, 0, 0,\ 0.0, 0, 0,\ 15:00:00)$, $(H,\ 2.0, 0, 0,\ 0.0, 0, 0,\ 15:00:01)$, ... , $(H,\ 2.0, 0, 0,\ 0, 0, 0, 15:00:11)$

- $seq101 = (A,\ 0.0,0,0,\ 0.1,0,0,\ 15:00:00),\ (A,\ 0.1,0,0,\ 0.2,0,0,\ 15:00:01),\ ...\ ,\ (A,\ 1.1,0,0,\ 1.2,0,0,\ 15:00:11)$
- $seq102 = (B,\ 4.0,0,0,\ 3.9,0,0,\ 15:00:00),\ (B,\ 3.9,0,0,\ 3.8,0,0,\ 15:00:01),\ ...\ ,\ (B,\ 2.9,0,0,\ 2.8,0,0,\ 15:00:11)$

By using these descriptions, we can express these various conditions:

- $seq101$: A is approaching to H
- $seq102$: B is approaching to H
- $seq101\ add_s\ seq102$: someone is approaching to H
- $seq101\ difference_s\ seq102$: someone is walking in the area of A's walk except B's walking area

This experiment shows the feasibility of our Arithmetic Operators.

4.4. Experiment 2: Effective Metadata Extraction with Direction Recognition for Collaborative Work

We consider the situation that two people A and B are discussing with whiteboard H and a chair C.

We can describe various conditions in the situation such as sitting side by side, standing in front of the whiteboard, sitting at the chairs by whiteboard.

By using our application described in Section 3, when any other people (including A and B) are moving in this room, we can immediately obtain these metadata stored in Sensor-Metadata Database in advance.

- $((A,\ 0,0,0,\ 1,0,0,\ 00:00:00)\ ,\ (A,\ 1,0,0,\ 2,0,0,\ 00:00:01))\ meets_s\ ((B,\ 2,0,0,\ 1,0,0,\ 00:00:00)\ (B,\ 1,0,0,\ 0,0,0,\ 00:00:01))$: face-to-face
- $(((A,\ 0,0,0,\ 1,0,0,\ 00:00:00)\ ,\ (A,\ 1,0,0,\ 2,0,0,\ 00:00:01))\ meets_s\ ((B,0,1,0,1,1,0,00:00:00)\ ,\ (B,\ 1,1,0,\ 2,1,0,\ 00:00:01))\ )\ meets_s\ ((C,\ 0,0.5,0,1,0.5,0,00:00:00)\ ,(C,0,0.5,0,1,0.5,0,\ 00:00:01))$: sitting side by side
- $(((A,\ 0,0,0,\ 1,0,0,\ 00:00:00)\ ,\ (A,\ 1,0,0,\ 2,0,0,\ 00:00:01))\ meets_s\ ((B,\ 0,1,0,\ 1,1,0,\ 00:00:00)\ ,\ (B,\ 1,1,0,\ 2,1,0,\ 00:00:01)))\ meets_s\ ((H,\ 1,0.5,0,\ 0,0.5,0,\ 00:00:00)\ ,\ (H,\ 1,0.5,0,\ 0,0.5,0,\ 00:00:01))$: standing in front of the whiteboard
- $((((A,0,0,0,1,0,0,00:00:00)\ ,\ (A,\ 1,0,0,\ 2,0,0,\ 00:00:01))\ meets_s\ ((B,0,1,0,1,1,0,00:00:00)\ ,\ (B,\ 1,1,0,\ 2,1,0,\ 00:00:01))\ )\ meets_s\ ((C,\ 0,0.5,0,1,0.5,0,00:00:00)\ ,(C,0,0.5,0,1,0.5,0,\ 00:00:01))))\ meets_s\ ((H,\ 1,0.5,0,\ 0,0.5,0,\ 00:00:00)\ ,\ (H,1,0.5,0,0,0.5,0,00:00:01))$: sitting at the chairs by the whiteboard

This experiment shows the feasibility of including the direction of the objects (people, a whiteboard, a chairs) with the algebra.

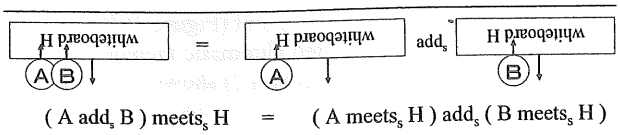

Figure 4. Experiment 3: Feasibility of Algebra for Reduction of Computational Complexity: case 1 (distributive property)

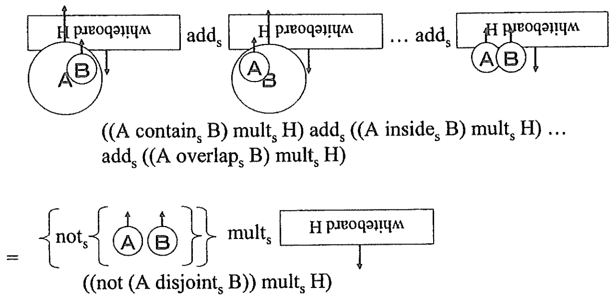

Figure 5. Experiment 3: Feasibility of Algebra for Reduction of Computational Complexity: case 2 (disjoint operator)

4.5. Experiment 3: Feasibility of Algebra for Reduction of Computational Complexity

We consider the situation that two people A and B are discussing near whiteboard H (Figure 4).

We can select one of semantically equivalent expressions by our algebra for the suitable condition such as lower computational complexity.

When two people A and B are discussing near the whiteboard H (Figure 4), we can describe this situation as following expressions by our algebra (distributive property):

- $(\ A\ add_s\ B\ )\ meets_s\ H$
- $(\ A\ meets_s\ H\ )\ add_s\ (\ B\ meets_s\ H\ )$

In this experiment, A, B and H are sequences defined in advance. When two people A and B have some spatial relationship, and A and B are at the whiteboard H (Figure 5). In this figure, the size of circles has no meaning. We can describe this situation as following expressions by our algebra:

- $((A\ contain_s\ B)\ mult_s\ H)\ add_s\ ((A\ inside_s\ B)\ mult_s\ H)\ add_s\ ((A\ equal_s\ B)\ mult_s\ H)\ add_s\ ((A\ meets_s\ B)\ mult_s\ H)\ add_s\ ((A\ covers_s\ B)\ mult_s\ H))\ add_s\ ((A\ coverdby_s\ B)\ mult_s\ H)\ add_s\ ((A\ overlaps_s\ B)\ mult_s\ H)$
- $((\ not_s\ (A\ disjoint_s\ B))\ mult_s\ H)$

5. Conclusion and Future Work

In this paper, we have presented a novel approach to time-space-direction algebra for collaborative work in ubiquitous environment. Our time-space-direction algebra is a mathematical form and a system describing physical and electronic objects with temporal, spatial, and directional features in ubiquitous environment. It enables us to describe any behaviors for physical and electronic objects in ubiquitous environment.

The main features of our approach are as follows. The first one is the description capability and reduction of computational complexity. The second is that by including the directions of objects in metadata precision for semantics extracted metadata is improved.

By adding direction and set-operators to temporal relationships[1] and spatial relationships[4], we define unified description form as time-space-direction algebra.

We also presented several applications of our algebra for collaborative work. We described the feasibility of our algebra by several experimental results for applications on intra-organization collaborative work.

As our future work, we will expand the functions for conflict resolution on our sensor-metadata database. We will perform the comparative and quantitative analysis especially for division operators. We will also design and implement applications of our time-space-direction algebra for inter-organization collaborative work. We also realize applications of our algebra to electronic objects with revision control, traceability of electronic documents via e-mails for intra- and inter- organization collaborative work,

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References

[1] J.F Allen.: "Maintaining Knowledge about Temporal Intervals," Communications of the ACM, No. 26, pp. 832-843 (1983).

[2] G. D. Abowd and E. D. Mynatt, "Charting past, present, and future research in ubiquitous computing," ACM Transactions on Computer-Human Interaction (TOCHI), Volume 7 , Issue 1 , pp. 29 - 58 , March 2000.

[3] E. F. Codd: "A Relational Model of Data for Large Shared Data Banks," Communications of the ACM, 13(6), pp. 377-387, 1970.

[4] M. J. Egenhofer, A. Rashid and B. M. Shari: "Metric Details for Natural-Language Spatial Relations," ACM Transactions on Information Systems, Vol.16, No.4, pp.295-321 (1998).

[5] T. Erickson: "Some problems with the notion of context-aware computing," Communications of the ACM, Volume 45 , Issue 2, pp. 102 - 104, February 2002.

[6] M. Fukumoto and M. Shinagawa: "CarpetLAN: A Novel Indoor Wireless(-like) Networking and Positioning System," in the proceedings of The Seventh International Conference on Ubiquitous Computing (UbiComp2005), 2005.

[7] M. Gerla and K. Xu: "Multimedia Streaming in LargeScale Sensor Networks with Mobile Swarms," ACM SIGMOD Record, Volume 32, Issue 4, Special section on sensor network technology and sensor data managment, December 2003.

[8] M. Hazas, , J. Scott, J. Krumm: "Location-aware computing comes of age," IEEE Computer, Vol. 37, Issue 2, pp. 95- 97, (2004).

[9] S. Hirose, S. Inoue, K. Yoneda: "The Whisker Sensor and the Transmission of Multiple Sensor Signals," Advanced Robotics, 4, 2, pp.105-117 (1990)

[10] A. Jaimes, N. Yoshida, K. Murai, K. Hirata, and J. Miyazaki: "Interactive Visualization of Multi-Stream Meeting Videos Based on Automatic Visual Content Analysis," In Proceedings of 2004 IEEE International Workshop on Multimedia Signal Processing, 2004.

[11] A. Jaimes and J. Miyazaki: "Building a Smart Meeting Room: from Infrastracture to the Video Gap," 1st IEEE International Workshop on Managing Data for Emerging Multimedia Applications (EMMA) in conjunction with 21th IEEE Conference on Data Engineering (ICDE 2005), 2005.

[12] M. Mani: "Understanding the Semantics of Sensor Data," ACM SIGMOD Record, Volume 32, Issue 4, Special section on sensor network technology and sensor data managment, December 2003.

[13] Y. Nishida, K. Kitamura, T. Hori, A. Nishitani, T. Kanade, and H. Mizoguchi: "Quick Realization of Function for Detecting Human Activity Events by Ultrasonic 3D Tag and Stereo Vision," Proc. of 2nd IEEE International Conference on Pervasive Computing and Communications, pp. 43-54, 2004.

[14] A. Schmidt, A. Takaluoma and J. Mantyjarvi: "Context-Aware Technology over WAP (Wireless Application Protocol), " Journal of Personal Technologies, Vol.4, No.4, pp.221-224, 2000.

[15] A. Sheth and W. Klas (eds.): "Multimedia Data Management – using metadata to integrate and apply digital media, " Mc-Graw Hill, 1998.

[16] U. Westermann, W. Klas: "An analysis of XML database solutions for the management of MPEG-7 media descriptions, " ACM Computing Surveys (CSUR), Volume 35 Issue 4 , December 2003.

[17] N. Yoshida, K. Hirata and J. Miyazaki: "An Automatic Generation of 3D Visualization for Holistic and Detail Relationships on e-Learning Environment," Proceedings of IEEE 2004 Symposium on Applications and the Internet - Workshops (SAINT 2004 Workshops) - International Workshop on Cyberspace Technologies and Societies (IWCTS2004), pp.446-451, Jan. 2004.

[18] N. Yoshida and J. Miyazaki: "An Automatic and Immediate Metadata Extraction Method by Heterogeneous Sensors for Meeting Video Streams," IEEE International Symposium on Applications and the Internet (SAINT 2005) - the International Workshop on Cyberspace Technologies and Societies (IWCTS 2005), pp. 446-449, IEEE Computer Society Press, Feb. 2005.