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A Global & Environmental Coral Analysis System with SPA-Based Semantic Computing for Integrating and Visualizing Ocean-Phenomena with "5-Dimensional World-Map"

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Abstract. Semantic computing is essentially significant for realizing the semantic interpretation of natural and social phenomena and analyzes the changes of various environmental situations. The 5D World Map (5DWM) System [4,6,8] has introduced the concept of "SPA (Sensing, Processing and Analytical Actuation Functions)" for global environmental system integrations [1-4], as a global environmental knowledge sharing, analysis and integration system. Environmental knowledge base creation with 5D World Map is realized for sharing, analyzing and visualizing various information resources to the map which can facilitate global phenomena-observations and knowledge discoveries with multi-dimensional axis control mechanisms. The 5DWM is globally utilized as a Global Environmental Semantic Computing System, in SDGs 9, 11, 14, United-Nations-ESCAP: (https://sdghelpdesk.unescap.org/toolboxes) for observing and analyzing disaster, natural phenomena, ocean-water situations with local and global multimedia data resources. This paper proposes a new semantic computing method as an important approach to semantic analysis for various environmental phenomena and changes in a real world. This method realizes "Self-Contained-Knowledge-Base-Image" & "Contextual-Semantic-Interpretation" as a new concept of *"Coral-Health-level Analysis in Semantic-Space for Ocean-environment*" for global ocean-environmental analysis [8,9,12,18]. This computing method is applied to automatic database creation with coral-health-level analysis sensors for interpreting environmental phenomena and changes occurring in the oceans in the world. We have focused on an experimental study for creating "*Coral-Health-level Analysis Semantic-Space for Ocean-environment*" [8,9,12,18]. This method realizes new semantic interpretation for coral health-level with "coral-images and coral-health-level knowledge-chart".

Keywords. Global Environmental Analysis, Semantic Computing, SPA, 5-Dimensional World Map System, Coral Analysis, Environmental Data Mining

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1. Introduction

The 5D World Map System and its applications create new analytical research environments with the SPA concept (Sensing, Processing and Analytical Actuation) for searching, sharing, integrating, analyzing and visualizing natural and social environmental phenomena and changes, as shown in Fig. 1. This system realizes "environmental analysis and situation-recognition" which will be essential for finding out solutions for global environmental issues. The 5D World Map System collects and facilitates a lot of environmental information resources which are characteristics of ocean species, disasters, water-quality and deforestation.

As conceptual modeling for making appropriate and urgent solutions to global environment changes in short and long-terms, "six functional-pillars" are essentially important with "environmental knowledge-base creation" for searching, sharing, integrating, analyzing and visualizing various environmental phenomena and changes in a real world.

(1) Cyber & Physical Space Integration,
(2) SPA-function,
(3) Spatio-Temporal computing,
(4) Semantic computing,
(5) World map-based visualization,
(6) Warning message propagation

As the actual implementation of the SPA architecture, 5D World Map System Project in Figure 1 has presented a new concept of "*Water-quality Analysis Semantic-Space for Ocean-environment*" for realizing global water-environmental analysis [8,9,18]. The semantic space and the computing method have been implemented as environmental knowledge-base creation with water-quality-analysis sensors for analyzing and interpreting environmental phenomena and changes occurring in the oceans in the world. We have focused on sea-water quality data, as an experimental study for creating "*Water-quality Analysis Semantic-Space for Ocean-environment*" [8,9].

We have introduced the architecture of a multi-visualized and dynamic knowledge representation functions in "5D World Map System [4,6,8]," applied to environmental analysis and semantic computing. The basic space of this system consists of spatial (1st 2nd and 3rd dimensions), temporal (4th dimension), and semantic dimensions (5th dimension, representing a large-scale and multiple-dimensional semantic space that is based on our semantic associative computing system (MMM)). This space memorizes and recalls various multimedia information resources with temporal, spatial and semantic correlation functions, and realizes a 5D World Map for dynamically creating spatio-temporal and semantic multiple views applied for various "environmental multimedia information resources."

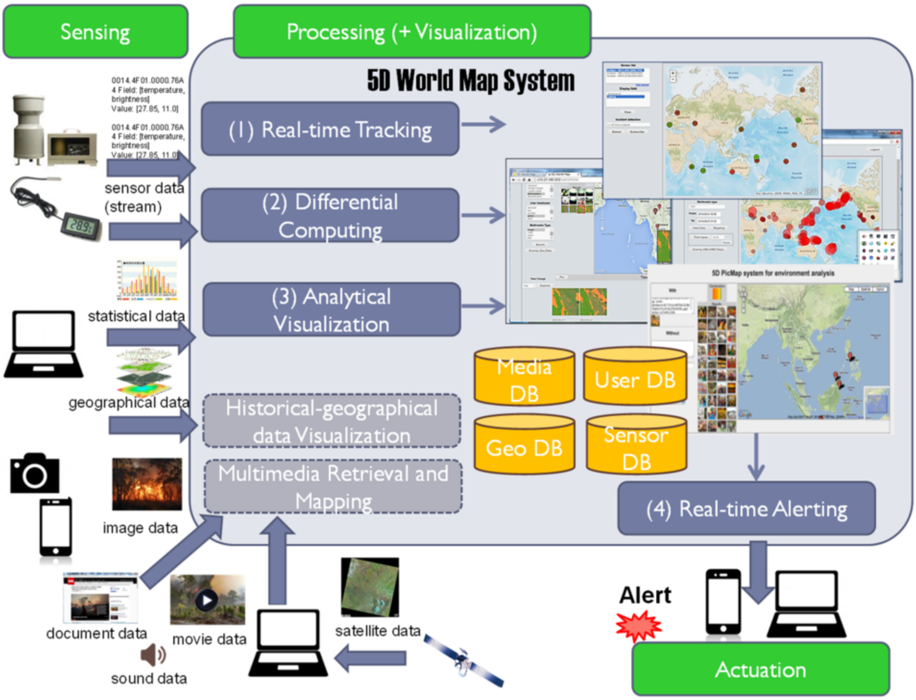

Figure 1. Basic SPA functions in 5D World Map System

2. Semantic Computing in MMM and 5D World Map System

We apply the dynamic evaluation and mapping functions of multiple views of spatio-temporal metrics and integrate the results of semantic evaluation to analyze environmental multimedia information resources. The MMM is a fundamental semantic computing model for the 5D World Map System, as a semantic associative search method [1,2,3] for realizing the concept that "semantics" and "impressions" of environmental multimedia information resources, according to "contexts". The main feature of this system is to create world-wide global maps and views of environmental situations expressed in multimedia information resources (image, sound, text and video) dynamically, according to user's viewpoints. Spatially, temporally, semantically and impressionably evaluated and analyzed environmental multimedia information resources are mapped onto a 5D time-series multi-geographical and semantic space. The basic system structure of the MMM and 5D World Map System is shown in Figure.2 and Figure. 3. The 5D World Map system, applied to environmental multimedia computing, visualizes world-wide and global relations among different areas and times in environmental aspects, by using dynamic mapping functions with temporal, spatial, semantic and impression-based computations [4,5,6,7,8].

2.1. Semantic Computing in 5D World Map System

We have introduced the architecture of a multi-visualized and dynamic knowledge representation system "5D World Map System," applied to environmental analysis and semantic computing in Fig.2 and Fig. 3. The basic space of this system consists of spatial (1st 2nd and 3rd dimensions), temporal (4th dimension), and semantic dimensions (5th dimension, representing a large-scale and multiple-dimensional semantic space that is based on our semantic associative computing system (MMM)). This space memorizes and recalls various multimedia information resources with spatial, temporal, and semantic correlation computing functions, and realizes a 5D World Map for dynamically creating spatial, temporal and semantic multiple views applied for various "environmental multimedia information resources."

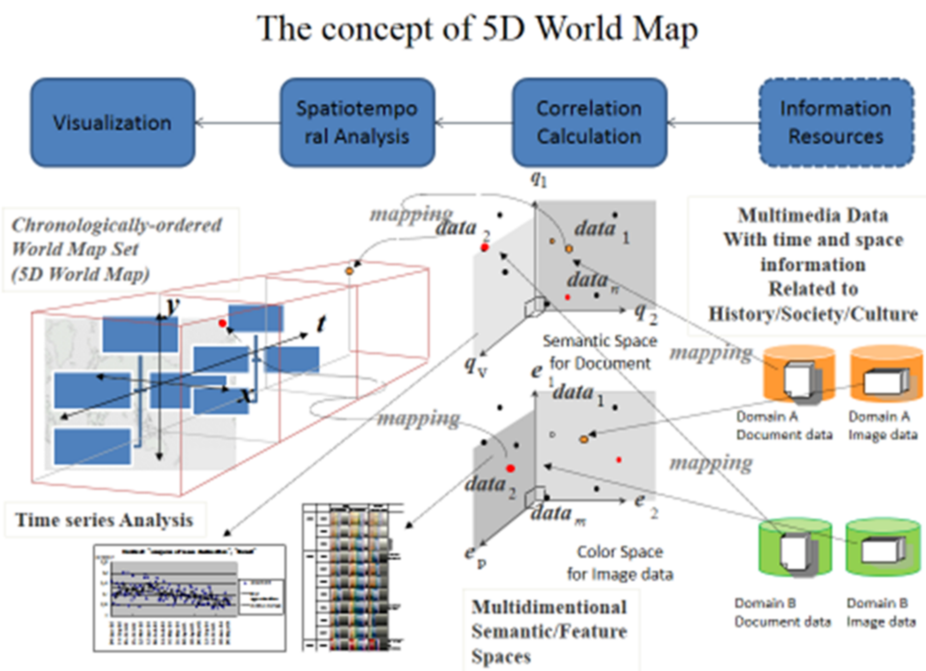

Figure 2. 5D World Map System for world-wide viewing and global environmental analysis

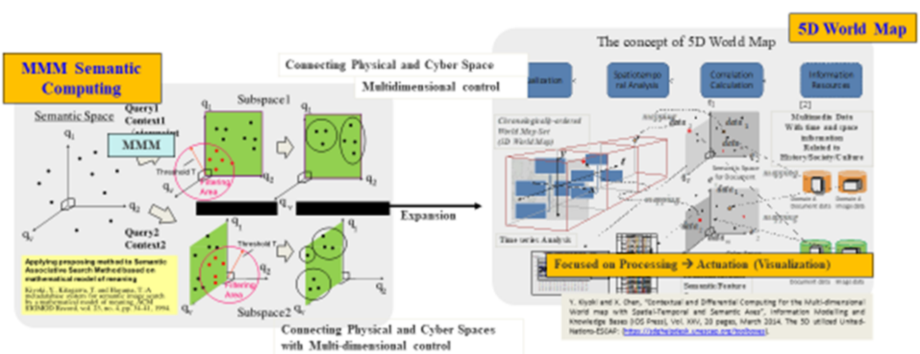

Figure 3. The system structure of MMM Semantic-Computing and 5D World Map System

2.2. SPA: Sensing, Processing and Analytical Actuation Functions in 5D World Map

"SPA" is a fundamental concept for realizing environmental systems with three basic functions of "Sensing, Processing and Analytical Actuation" to design environmental systems with Physical-Cyber integration. "SPA" realizes a significant function to detect environmental phenomena with real data resources in a physical-space (real space) in 5D World Map, maps them to cyber-space to make analytical and semantic computing, and actuates the analytically-computed results to the real space by visualization for expressing environmental phenomena with causalities and influence. This concept is applied to global water-quality and coral-analysis with semantic computing in 5D World Map System, as shown in Fig. 4, 5 and 6.

Input image = purple coral, Categories = coastal waste, SDG14, ocean pollution

Figure 4. Global Environmental Analysis and Visualization of "Coral" in "5D World Map System

3. Semantic Computing for Coral-health-analysis in MMM

A MMM-based semantic computing method [1,2,3] is applied to coral health-level analysis with a knowledge base in a coral image. This method realizes automatic semantic interpretations of Coral health-level with a coral-image containing the knowledge base of coral-health. We use "Coral-health-chart [26]" as an example, to express color-health-level correspondences

This method consists of three essential elements.

(1) Coral image

(2) "Coral-health-level-Color-correspondence chart" as a knowledge-base

(3) Semantic distance computing between "Coral-color" and "Coral-health-level-Color-correspondence chart"

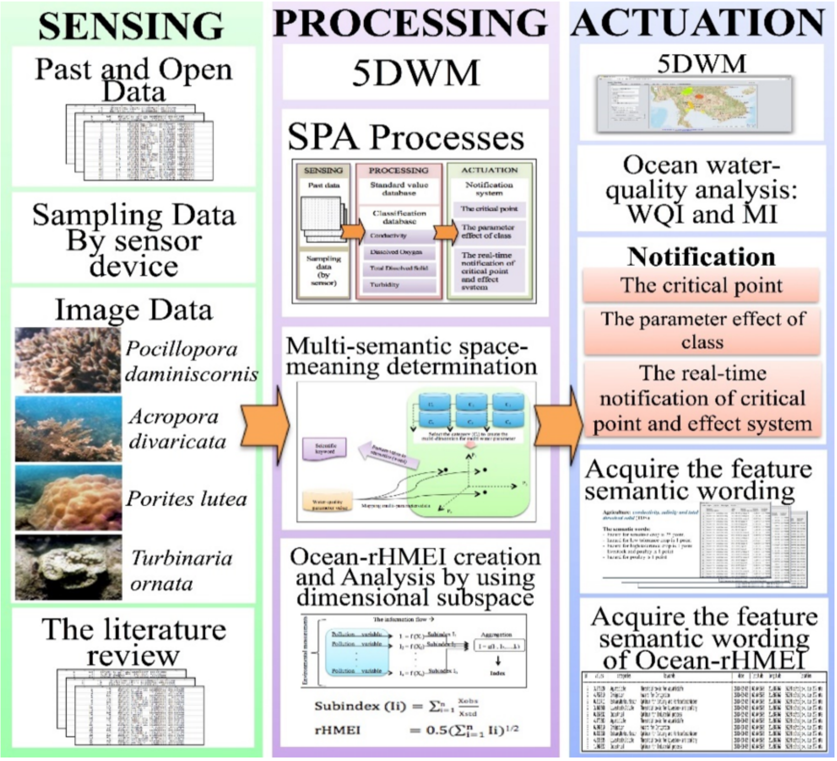

Figure 5. SPA functions for Ocean Environment-analysis with multi-dimensional control in 5D World Map System [9,18]

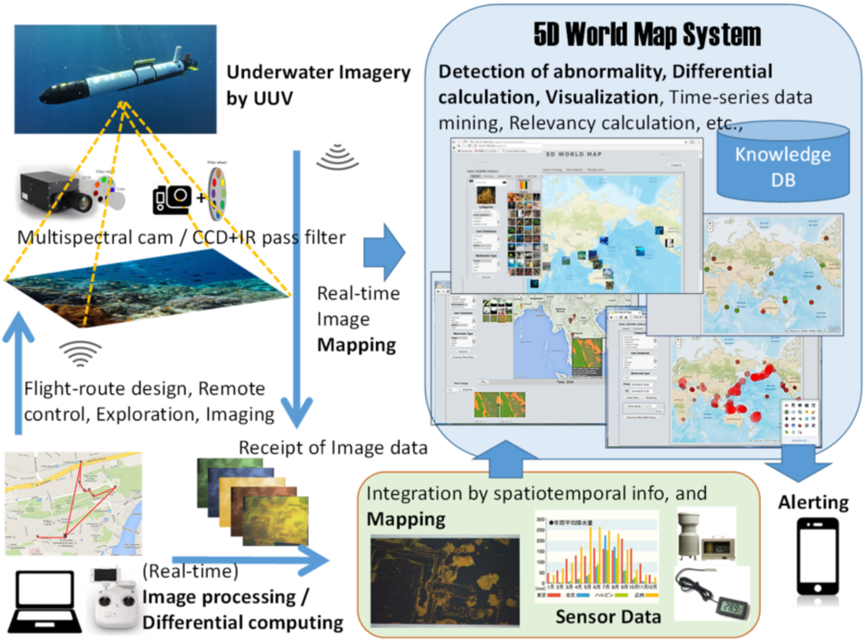

Figure 6. SPA functions for Underwater Environment-Images in 5D World Map System[12,18]

The overview of this method is shown in Fig. 7, as “Self-contained-Knowledge-Base-Image” & “Contextual-Semantic-Interpretation Algorithm”

3.1. Data structure

The basic data structure of this method is defined as follows:

(Data-structure-1) “Coral-Image-with-chart” with “Target-Coral” and “Coral-Chart”

(Data-structure-2) “Target-Coral”: Coral-color table (81-pixels-coral-color vector (3-color-elements (RGB) between “coral-pixel-id” and its “coral-color vector”

(Data-structure-3) “Semantic Interpretation Knowledge Base”: (pairs of “color and its meaning”) :
Chart-color table (24 chart-color vectors (3-color-elements (RGB)) between “chart-color” and its “chart-color vector” with meanings)

3.2. Basic Functions and “Contextual-Semantic-Interpretation Algorithm”

The two basic functions are defined as follows:

(1) “Semantic-Distance-calculation" between “coral-color vector” and each of “chart-color vectors”

(2) Ranking-calculation in correlations among “semantic-distances” as “semantic-ordering” (ascending-order or descending-order).

“Contextual-Semantic-Interpretation Algorithm” for “Self-Contained-Knowledge-Base-Image” is defined in the procedure:

(Step-1) It receives “Coral-Image-with-chart” including “Target-Coral” and “Coral-Chart” as a single-image (Self-Contained-Knowledge-Base-Image) is as Fig. 7,

(Step-2) Coral-color analysis:

(Step-2-1) It searches for “Target-Coral” in “Coral-Image-with-chart”, and describes horizontal and vertical lines for specifying “coral-pixel-id”, as Fig. 8,

(Step-2-2) It accesses to each coral-pixel, reads and makes the pixel values (ex, R, G, B or H, S, V) as a “coral-color-vector”,

(Step-2-3) It creates “Coral-color table” consisting of “coral-pixel-id” and “coral-color-vector” for every coral-pixel.

(Step-3) Chart-color analysis:

(Step-3-1) It searches for “Coral-Chart” in “Coral-Image-with-chart”, and describes horizontal and vertical lines for specifying “chart-color” and its “chart-color vector” with meanings,

(Step-3-2) It accesses to each chart-color, reads and makes the chart-color values as “chart-color-vectors”,

(Step-3-3) It creates “Chart-color table” consisting of “chart-color” and “chart-color-vector” with meanings for every chart-color.

(Step-4) Semantic interpretation with “semantic-distances” between “coral-color vector” in Step-2-3 and each of “chart-color vectors” in Step-3-3:

(Step-4-1) For each of “coral-pixel-id’s”, it calculates distances between “coral-color vector” and each of “chart-color vectors” as “semantic-distances” of the “coral-pixel-id”, (Step-5) Ranking-calculation among "semantic-distances" as "semantic-ordering" (ascending-order or descending-order) (Step-5 assigns a "meaning" to each "coral-pixel-id", as the result of semantic-interpretation for "Self-Contained-Knowledge-Base-Image"):

(Step-5-1) For each of "coral-pixel-ids", it calculates a ranking of chart-colors among "semantic-distances", as "semantic-ordering" (ascending-order or descending-order), and extracts the corresponding meaning to the top-ranked "chart-color",

(Step-6) Aggregation Function for meanings of coral-pixels:

(Step-6-1) It integrates all the calculation results of "semantic-distances" for each "coral-pixel-id" to each chart-color obtained in Step-4, as an integrated "coral-pixel-id & chart-color table with semantic-distances",

(Step-6-2) For each chart-color in "coral-pixel-id & chart-color table", it computes "max-value", "min-value" and "average-value" for all the semantic distances to every coral-pixel-id, and makes ranking of chart-colors (each of them has meanings) according to "max-value", "min-value" or "average-value", as the ranking of meanings interpreted for all the coral-pixel-ids. That is, the top-ranked meaning is interpreted as the meaning of the target-coral

Figure 7. "Self-contained-Knowledge-Base-Image" & "Contextual-Semantic-Interpretation"

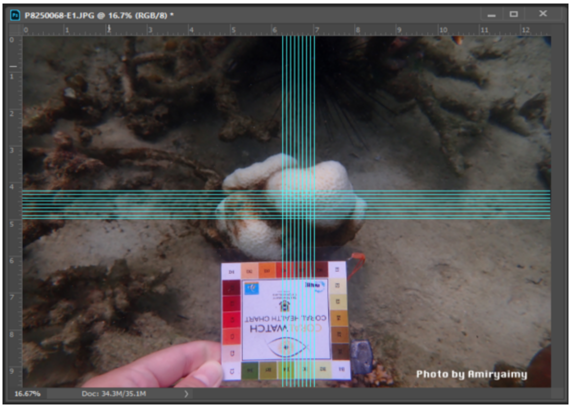

Figure 8. "Self-contained-Knowledge-Base-Image" & "Contextual-Semantic-Interpretation" with extracting Coral-color and "Coral-Chart" pixels

The execution result of “Self-contained-Knowledge-Base-Image” & “Contextual-Semantic-Interpretation” with extracting coral-color and “coral-chart pixels” is shown in Fig. 9. This result gives the meaning of the coral health-level as “E2” (corresponding to “damaged-coral in health-level”), according to the distance ordering of “minimal value” between coral-color and the closed color, “Color-E2(“damaged-coral in health-level”) in the coral-chart. This method realizes the automatic semantic-interpretation of the health-level of Coral with the “Self-contained-Knowledge-Base-Image” & “Contextual-Semantic-Interpretation.”

color	max-value	“min-value”	average-value
E2	199.173291382153	5.3851648071345	92.8795932168451
B2	180.549162279973	8.30662386291807	78.8662052947991
B3	157.676884799263	14.7309198626562	68.5533171328608
B6	211.011848008589	16.0312195418814	115.848366433731
C2	189.886808388577	20.6639783197718	89.7862646632142
E3	149.435604860421	22.0907220343745	71.4354194997922
B5	179.724789609002	36.7287353444139	96.229974266913
C1	229.150605497782	36.8374809127877	125.545628555143
B1	219.64289198606	38.7556447501522	119.715940857096
D1	224.784341091634	39.6610640301039	123.489598143384
D2	152.558185621093	42.0119030752	83.2472631277141
E1	233.096546520964	42.8602379834737	130.364768299334
B4	136.97810043945	43.3820239269677	81.6315504391287
E6	240.459975879563	45.3872228716409	145.859388823329
E5	198.597583066864	56.4446631666803	117.369279848312
D6	249.713836220583	63.7573525171803	157.66160136726
C6	248.233760798164	67.705243519243	157.742461708311
E4	155.058053644433	69.9857128276908	103.590703682212
D5	232.036635038521	73.3552997403732	148.155810217487
C5	224.385828429516	90.27181176868	148.719759483493
D3	151.479371532892	98.9393753770459	123.909610409952
D4	209.461213593352	107.060730429042	146.596739253442
C3	188.430358488222	107.429046351534	137.932225797416
C4	222.117086240568	127.334205930692	164.516483142756

Figure 9. “Contextual-Semantic-Interpretation” of “Self-contained-Knowledge-Base-Image” & “Contextual-Semantic-Interpretation” with extracting Coral-color and “Coral-Chart” pixels

The essential feature of this method is that this semantic-interpretation is not affected from the photography conditions of photography-apparatus (camera) and natural situations of Hue, Saturation and Values under the Ocean water, because the image in this method includes both the target Coral and the Coral-Chart in itself, and the photography conditions are totally the same between them. That is, this method is not affected from photography conditions, and it does not need camera-calibration in photography in Hue, Brightness and Saturation between the target Coral and the Coral-Chart. This feature makes semantic-interpretation full-automatic with “Self-contained-Knowledge-Base-Image”. The importance in this semantic computing is that the Coral-Chart itself, that is the knowledge base including the meanings of colors in health-levels, is existing inside the target coral image. This essential feature leads to automatic semantic-interpretation without camera-calibration.

The possibility of misinterpretation in “semantic-distances” computing must be considered, when this method uses the RGB color model. The RGB color model does not have linearity to the perception with Human-eyes, that is, the comparisons beween coral-pixel and each chart-color are not linear in the distance of colors. To make lineality closer to the perception with Human-eyes, this method is realized in 3-color-elements in the HSV (Hue, Saturation, Value) color model, instead of the RGB color model. HSV is mostly used in color system researchers [13-17] and is closer to Human-perception in colors than RGB. In order to convert RGB to HSV, it can be calculated by using HSV conversion formula [17] or using online color converters.

The result of damaged coral shows "Color-E2" at the coral health-level in Fig 10. The result of RGB is shown in Fig 11, and the distance between coral-color and the closed color in coral-chart is "Color-B6" according to the minimal value while the result of HSV in Fig 12 shows "Color-E2" in the minimal value. Then, HSV shows closer in the result than RGB, in case of misinterpretation in RGB. In summary, those results show the differences between the color systems (RGB or HSV), and the semantic distance in HSV shows the effectiveness in semantic distance computing of this method.

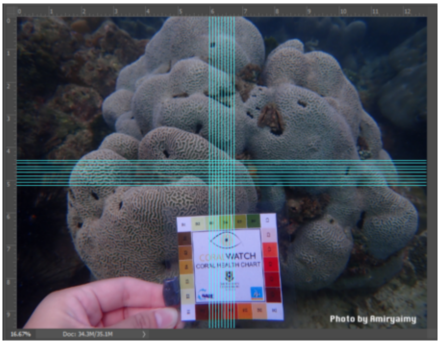

Figure 10. Damaged coral in coral health level at E2

color	max-value	"min-value"	average-value
B6	143.436397054583	15.6843871413581	53.9530082764298
E6	113.141504320917	23.5372045918796	52.2947725655229
D2	179.783202774898	26.229754097208	105.050060069544
D6	155.206314304541	32.0312347560939	80.9509797660195
E3	194.887146831185	36.7695526217005	116.012734824335
B5	101.764433865668	41.1096095821889	60.5440201042771
E5	105.995282913911	44.1134900002256	66.7361943931025
C6	167.406690427832	50.0699510684802	97.4038646615865
E4	141.495582969929	50.1697119784437	85.572961931423
B4	152.072351201657	51.7397332811061	88.153219620497
C3	173.856262469892	54.4609952167604	127.88716462633
D5	149.361976419703	60.6382717431821	88.5311896581875
B3	226.192395981828	65.00769185258	146.684142614392
E2	229.322916430086	65.9545297913646	149.154457736076
D3	141.911944528993	70.3491293478462	107.061472382264
D4	142.323574997258	93.3005894943864	109.566790703382
C5	166.72432336045	93.8775798580257	115.962469146496
B2	258.149181676022	95.1104620953973	177.993696839244
C2	264.049237832644	103.213371226794	184.514200836705
D1	261.218299512113	107.694010975541	184.072133009289
C4	170.393661853955	116.172285851661	137.423837778023
E1	274.901800648886	118.110118110177	196.728808812628
C1	301.15776596329	142.256810030311	222.318845971243
B1	311.117341207461	151.297719744879	231.960252595281

Figure 11. The result of RGB color model

color	max-value	“min-value”	average-value
E2	17.5569615257933	2.10612650549263	6.31762959664565
B6	12.5808920997929	2.19201593116456	6.39178314184013
E6	19.2400953511202	2.59927273045414	12.7081295615523
C3	19.911280661172	2.67169663296457	9.83780652698295
E3	16.6462076525158	3.07620746204729	10.4944454715758
D2	18.614161557258	3.10368116171445	12.8329250384822
B3	12.8418180694141	3.19913668044159	7.34225025413962
B2	12.2167221280738	3.50272344440962	7.0180543996998
C2	14.5340397117224	3.66093731078246	5.9251992689127
D4	20.1898764369652	4.08300378180018	10.0474629296558
E5	18.0692860479916	4.45330238797583	12.4111880101652
E1	13.5860454292085	4.63171603361099	6.63766241940873
D5	19.833681264057	4.63542752720645	9.23234830474871
D1	13.3733878102211	4.77153983025864	6.63191130593785
B5	16.0475570072356	4.81755900775598	10.1462423314754
D6	18.948684513604	4.81893534182752	8.02499275731741
C1	13.5621368550884	5.03598786866439	7.04735755271535
E4	17.5214441479184	5.07105939170588	12.09928801166
B1	13.7793964600946	5.07241033263328	7.14802014322634
C4	20.5014728780713	5.23527274022288	11.1633815397469
B4	15.0575130567888	5.4354499776699	9.70072280774479
C5	20.4880430672202	6.01199655098454	10.9362854879886
C6	19.8877963039989	6.01212213159579	9.82187295447358
D3	19.0145659234063	6.96028363526647	13.7586714234836

Figure 12. The result of HSV color model

4. Global and Environmental Coral-Analysis and Visualization in 5D World Map

This section focuses on semantic computing for Coral analysis with a “**Semantic-Interpretation method”.** We realized the experimental system using SPA functions in 5D World Map and applied the coral-image data. Coral-leaf analysis has been done in a lot of coral-leaf research projects, as discussed in [18-25]. One of the important applications is “Global Environment-Analysis,” which aims to evaluate various influences caused by natural disasters in global environments. We have constructed "SPA-based Global-Environment-Analysis System” for sharing and analyzing environmental situations with MMM functions applied to “environmental multimedia data sharing,” as a new global system of collaborative environment analysis [1-5]. This system creates a remote, interactive and real-time and academic research exchange among different areas. We visualized the important factors of water-quality for coral on 5DWM which is shown in Fig. 13 – Fig. 16.

We have realized several experiments of SPA functions in 5D World Map for Sea-Water Quality Data in “Coral Areas” of “Si Chang-Islands (http://www.arri.chula.ac.th/). The experimental system uses SPA functions in 5D World Map and applied the collected seawater quality data from the spots in Si Chang-Island [11-12]. The major issues of seawater quality in Si Chang-Islands is an effect of seawater pollution to coral life. For the major issue, we integrate the following data sources from Si Chang-Islands, and water quality data period from 2011 – 2015, which are collected from Aquatic Resources Research Institute, Chulalongkorn University, Thailand. We uploaded them to 5D World Map, as text data with spatial and temporal data. For finding the effect of seawater pollution to coral life, we measured several water parameters of temperature, pH, Suspended Solid, Ammonia, Nitrate and Phosphorus, which are important factors in term of an essential nutrient, quantities and equilibrium supported of coral life.

Input image = dead coral, Categories = coastal waste, SDG14, ocean pollution

Figure 13. Global Environmental Analysis of "Coral" in "5D World Map System: (a) Image search by color information, (b) Spatiotemporal analysis (global overview of geographical distribution and the time-series change), and (c) Example of image data collection

Input image = colorful coral, Categories = coastal waste, SDG14, ocean pollution

Figure 14. Global Environmental Analysis of "Coral" in "5D World Map System: (a) Image search by color information, (b) Spatiotemporal mapping in the global overview of geographical distribution

Input image = purple coral, Categories = coastal waste, SDG14, ocean pollution

Figure 15. Global Environmental Analysis of "Coral" in "5D World Map System: (a) Image search by color information, (b) Spatiotemporal analysis (global overview of geographical distribution)

Input keyword = "bleached coral", Categories = all (no specification)

Figure 16. Global Environmental Analysis of "Coral" in "5D World Map System: (a) Image search by color information, (b) Spatiotemporal analysis (global overview of geographical distribution)

5D World Map memorizes those seawater quality data in combination of environmental coral-image data to make semantic analysis of Ocean environment in this area with context-oriented semantic computing.

5. Conclusion

This paper presents a new environmental-semantic computing system for coral-analysis in water-quality and image spaces with "Multi-Dimensional World Map." The main feature of our system is to realize semantic computing among different spots related to water-quality and coral-image databases. This system is based on the concept of "*Coral-Analysis space*" for realizing global environmental analysis. In our system, semantic computing is realized in the multiple dimensional orthogonal semantic space with semantic projection functions. This space is created for dynamically computing semantic equivalence, similarity and differences among water-quality data resources. We have applied this system to Coral-image data analysis in the experiments in the Pacific Ocean Area.

This system realizes a "global-semantic analysis and observation for environmental issues" with the integration of remote, interactive and real-time environmental and academic research knowledge and information resources. We have also presented Environmental Multimedia Computing system and the 5D World Map System, as an international and environmental system with Spatio-temporal and semantic analysers.

As our future work, we will extend this semantic computing system to new international and collaborative research and education for realizing mutual understanding and knowledge sharing on global environmental issues in the world-wide scope.

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