A Multi-view and Multi-interaction System for Digital-mock up's collaborative environment

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Abstract

The current industrial PLM tool generally relies on Concurrent Engineering (CE), which involves conducting product design and manufacturing stages in parallel and integrating technical data for sharing among different experts in parallel. Various experts use domain-specific software to produce various data. This package of data is usually called Digital mock-up (DMU), as well as Building Information Model (BIM) in architectural engineering [SNA12]. For sharing the DMU data, many works have been done to improve the interoperability among the engineering software and among the models in domains of mechanical design [FR07] and eco-design [RRR13]. However, the computer-human interaction (CHI) currently used in the context of CE project reviews is not optimized to enhance the interoperability among various experts of different domains. Here the CHI concerns both complex DMU visualization and multi-users interaction.

Since the DMU has its multiple representations according to involved domains [Par04], therefore when various experts need to work together on the DMU they may prefer their own point-of-view on the DMU and proper manner to interact with the DMU. With the development of 3D visualization and virtual reality CHI technology, it is possible to devise more intuitive tools and methods to enhance the interoperability of collaboration among experts both in multi-view and multi-interaction [NA13] for co-located synchronous collaborative design activities.

In this paper, we discuss the different approaches of displaying multiple point-of-views of DMU and multiple interactions with DMU in the context of 3D visualization, virtual reality and augmented reality. A co-located collaborative environment of CHI supporting system is proposed. This collaborative environment allows the experts to see respectively the multiple point-of-view of the DMU in front of a unique display system and to interact with the DMU in using different metaphors according to their specific needs. This could be used to assist collaborative design during project review where some decision on product design solution should be made.

Categories and Subject Descriptors (according to ACM CCS): J.6 [Computer-Aided Engineering]: Computer-aided design (CAD), Computer-aided manufacturing (CAM)—Collaborative design; H.5.2 [INFORMATION INTERFACES AND PRESENTATION]: User Interfaces—Multi user interface, display, virtual reality

1. Introduction

Concurrent engineering (CE) has become a widely used approach in industry. In compare with traditional sequential engineering (SE), CE has changed the modality of Product Lifecycle Management (PLM) from sequential to parallel. PLM activities, including design, analysis, manufacturing, recycling and maintenance, are well arranged with proper overlaps at the same time [SE98]. It is an integrated product development process strategy with which everyone involved works collaboratively in parallel in order to reduce the overall product development time [SR09]. The scientific contributions of this paper are: (a) A concept of computer-human interface (CHI) supporting multi-view and multi-interaction for collaborative design. (b) A state of the art of multi-view display and multi-interaction. (c) The appropriate solutions have been described and proposed.

1.1. Point-of-views of DMU

Every product lifecycle activity of CE needs expert and domain-specific computer tools. These tools mainly contain the computer aided design (CAD) of product, computer aided engineering (CAE) for physical analysis, computer aided manufacturing (CAM) for all operations of manufacturing and other software from different domains. Various experts use domain-specific software to produce various data [Par04]. Each expert considers his/her own contribution to the product as one point-of-view (POV) of the whole product development according to his/her expertise. Then he/she shares his/her information with other experts by sending the data produced by the domain-specific software into a global database [GD07]. The large package of data itself, together with the product structure and attributes of this data package builds up a Digital mock-up (DMU) in industrial engineering. It concerns the generation and management of digital representations of physical and functional characteristics of industrial products. Building Information Model (BIM) is similar to DMU for architectural engineering [SNA12]. BIM model is also a set of interacting policies, processes and technologies containing building design and project data in digital format throughout the building's life cycle [Pen06].

DMU can present data with different meaning and form a series of data in different modalities. E.g. in automobile engineering, a sketch, 3D parts as well as an assembly of them, a point cloud as well as mesh model in reverse are all possible representations of DMU, as shown in Figure 1. That means a DMU has multiple representations. Meanwhile, from the expert's position, every expert has his own POV of the DMU. The POV decides which data in the DMU will be put out by expert. If two experts focus on a same DMU representation, e.g. a mesh model representation, they will have the same data format. But their POVs may still be different because their specific requirement e.g. one expert for the whole mesh model while another only for a tiny sub model. Their POVs of this representation is different. This also causes the differences of data resource and data quantity.

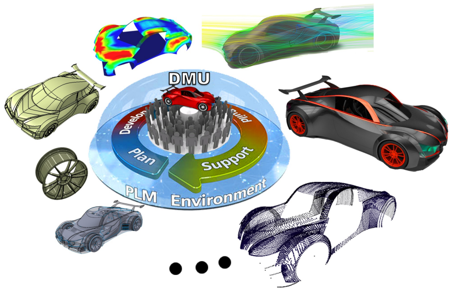

Figure 1: *During entire PLM, multiple experts work with one unique DMU. Each expert has a POV of DMU, such as a sketch, a single part, an assembly of a component or the whole car, CAE model for simulations, exterior design and a point cloud or mesh model in reverse engineering.*

As described above, DMU offers experts many representations. It usually provide geometry data to CAD tools for part design, interference examination between parts and assembly [WLG09], assembly process design, maintenance design, kinematics simulation; provide mesh and constrain data to CAE tools for Finite Element Analysis (FEA) such as structural simulation or Computational fluid dynamics (CFD) calculations in the aerodynamics or thermal simulations; provide geometry and material data to CAM tools for numerical manufacturing process management [FSLF11]. For experts, they might have various POVs of each representation. This will result in various POVs of DMU.

1.2. Collaboration

Since the concept of CE requires the simultaneous progress of all engineering aspects, each expert should communicate with others in real time on the status of the product development that he/she is working [MMOR13]. Thus, the communication among both the domain-specific softwares and the experts is increasingly important. Many works have been done to improve the interoperability among engineering software and among the models [BN08]. E.g. [FR07] and [RRR13] proposed a model-based approach for the design of mechanical products. The model exported by several expert tools can be shared as collaboration knowledge in domains of mechanical design and eco-design.

In architecture engineering, BIM software could integrate all the domain specific representations of a building along its lifecycle in one information technology (IT) platform and save them into a unique file. In compare with using several elementary domain specific softwares, BIM software overcomes the problem in terms of interoperability among them [GJG10].

Since product lifecycle activity of CE depends not only on computer tools but also on the factor of human beings as well. As interoperability is the communication among tools, collaboration is the communication among experts. Since interoperability among tools has been improved, the facilities on communication among experts have also to be enhanced.

During the product development, the activity that mostly needs the collaboration of all experts of PLM is project review. It is arranged regularly as milestones during collaborative design. Meeting support systems [KS95] can be employed to support creative activities in collaboration. The development of the tools to support design during project reviews is also important [Joh88].

Project review during product development can strongly summarize the current work and assign the work of next stage by making modifications and proposing solutions to both strategical and technical details [SE98]. The content for project review normally relies on the information generated from DMU [FSLF11]. A DMU provides different information representations and each expert can choose the one from his/her POV. Simultaneously the experts exchange their opinions of several domains according to their specialities [PFGL08]. Then they could discuss and communicate in real time.

To enhance the collaboration among experts from different domains to communicate with DMU, a novel CHI has been taken into consideration. CHI mainly concerns both complex DMU visualization and multi-users interaction [CNM*05]. In this article, we aim at the visualization technology of DMU's different POVs and multi-interaction technology for multiple users activities applied in a co-located synchronous project review support system.

1.3. Multi-view visualization

Visualization is a very important part of CHI in the context of collaboration. As human beings, visualization is the most effect way to accept information, to understand the intention and to take a decision.

The normal co-located synchronous project review support system is with private view devices like laptops and tablet computer. Every expert gathers together in a meeting room with their laptops in their own hands. A screen is also usually available to show shared information among the experts; one can display the content from his/her private view on the shared screen in order to diffuse the information to everyone. As we can imagine, everyone wants to show others the opinion in his/her domain. But the fact is when one sees others' view with the information not familiar with, he/she still cannot understand those domains. This is because the experts from all other domains with all different technical, different educational and cultural level, even simply different language backgrounds [CNM*05]. They don't have the same knowledge in their mind and cannot exchange information immediately in real time. This reduces the effect of communication and increases the difficulty of discussing and negotiating with others.

On the other hand, many commercial DMU and BIM platforms can integrate design, analysis and manufacture. However, an expert only uses a part of the platform to finish his work. Separate displays, like using single laptop or screen wall that put several separate screens together, display different domains of information separately. Expert has to exchange eyes and body to deal with the information fragments. This may reduce the expert's concentration psychologically and increase the possibility of misunderstanding and complex of communication [ZW14]. When attending a project review, in which facial expressions and hand gestures interaction are important to express ideas among each other, experts requires more face-to-face communication. If an expert can be presented only with his own POV in a shared visual space with other experts, he can avoid switching eyes between another expert and himself. This will help the expert to communicate and collaborate [ABM*97] with others and also to overcome the sense of isolation that happens when experts use their own tool in his laptop to attend this project review. Thus, a co-located multi-view DMU representation support system is proposed.

We can imagine an ideal collaborative working status, which is presented on Figure 1.

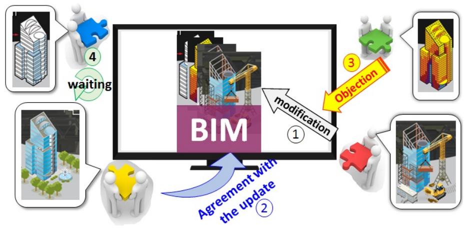

Figure 2: *A case study of usual collaborative situation described by BIM experts working collaboratively using one screen in real time:*
Expert 1, field of expertise: construction, proposed a modification of the BIM model;
Expert 2, field of expertise: urban engineering, obtains the modification effected in urban POV of DMU in real time, expressed approval of Expert 1;
Expert 3, field of expertise: structure analysis, finds a conflict in the building structure POV of DMU, expressed an opposition and conducted a further discussion with Expert 1;
Expert 4, field of expertise: building design, has got not much change in his POV, chose to stay and wait for the discussion result.

Many stereoscopy technologies have been widely used to represent 3D images. For DMU and BIM, normally standard commercial tools are widely used: CATIA, Autodesk Inventor, AutoCAD, Revit, Civil 3D, MACAO (Microstation), Vianova Virtual Map, etc. With the development of virtual reality technology, the approach of representation of DMU became diverse. In related work of this article, we discuss the main stereoscopy technologies and their approach in extending to multi-view 3D.

1.4. Multi-interaction

Interaction allows human and machine to communicate with each other. Here we concern about how different experts interact with the various POVs of DMU. The multiplicity of interaction is an important criterion of CHI. Intelligent CHI will allow users to interact with multiple metaphors and interpret one metaphor to more than one single command [MHPW06].

However, multi-Interaction has two levels of meaning. From the technical level, multi-interaction means multiple interaction devices [SKV14, Her08]. As far as we could imagine, 3D visualization and vision techniques, 3D sound

Table 1: *Various experts can choose the same metaphor to use to interact with one project. The same result or not indicates whether a collaborative multi-interaction has an alternative meaning.*

Same Metaphor	Same Object	Same Result	Multiple Meanings
×	×	×	N
×	×		*Y*
×		×	N
×			N
	×	×	*Y*
	×		N
		×	N
			N

technologies and haptic devices like force feedback and tactile feedback, all of these devices could give the user one or more interaction methods with the DMU. They bring the user not only the visual perception, but also the perception of immersive sound and touching effect on virtual object [Mer10]. Multi-interaction can support a variety of creative work for group experts' alternating activities like collaborative discussions and presentations [GJPR10].

From an interaction metaphor level, multi-interaction means that different user-defined metaphors can be conducted in real time [WMW09]. As listed in Table 1, when interacting, two experts may choose metaphors to use on objects and obtain some results. We put a "Y" in the table for the situation that various metaphors result in alternative meaning. So multi-interaction can be summarized as: One interact metaphor can be used by different experts and generate different meaning according to the experts' domains [PU97]. Similarly, two experts interact with the same object but their interaction metaphor (gesture) may be different.

Each expert could choose interaction metaphors different from the ones chosen by the others in virtual navigation and manipulation of the model [BCC*08]. A series of problems deriving from interaction metaphors will be discussed in the future work. Only a group manipulation interaction metaphor problem will be mentioned here to illustrate.

Experts manipulate the model by modifying (addition, deletion, rearrangement etc.) its parts or the elementary sub models [BISGM02, WL06, MZTZ04]. E.g. modifying airplane rivets, building or deleting pipes. One short interaction should be taken instead of repetitive interaction with relative tasks. Group manipulation for a certain category of objects according to certain rules will reduce the length of intervals of operation.

Many 3D stereoscopy technologies have been widely used to represent 3D images. For DMU and BIM, normally standard commercial tools are widely used: CATIA, Autodesk Inventor, AutoCAD, Revit, Civil 3D, MACAO (Microstation), Vianova Virtual Map, etc. With the development of virtual reality technology, the approach of representation of DMU became diverse. In related work of this article, we discuss the main 3D stereoscopy technologies and their approach in extending to multi-view 3D.

2. Related work

2.1. Multi-view

Normal device for display provides one 2D view to the user, like television, computer and smartphone. Compared to single view display, multi-view visualisation offers more views for more users. Two slightly different 2D views for human eyes can be fused in the human brain for having stereoscopic POV [Dod05]. Since the geometry model of a DMU is usually in 3D format, it will be at least four 2D views for two users to have 3D POVs of a DMU. Many approaches and their applications have proposed multi-view solutions, as well as 3D multi-view solutions if a 3D POV is in need. They may come from the improvement of existing single view and 3D single view. But the purpose of all these approach is to increase the number of views.

[Mis09] and [NUH*10] applied the glasses based stereoscopy technology to a multi-view approach. Two original shutter glasses or polarized glasses are restructured by putting two left eye lenses together and two right eye lenses together as two new pairs of glasses. Each user can see one view of the former 3D image through new glass in 2D. This approach is very practical to display a POV in 2D view to multiple users.

[MFP08] describes how to make screen-based autostereoscopic systems display two 2D views for two POVs. The naked 3D parallax-barrier or lenticular sheet screen let the user see one image with two eyes but with slight difference in vertical direction. Adding more images and resetting the parallax in vertical direction, each user works as one eye in 3D display. He/she can have a POV of 2D image in a stable position and from a fixed angle.

[TV15] and [Dis14] improved the shutter glasses technology accompanied with a screen with high refresh ratio of 240Hz. Each of the four eyes from two users is displayed in the ratio of 60Hz, which is the lowest ratio for human being to see clearly. And four eyes could be displayed in sequential separately. In total, four 2D views provide two 3D POVs to the two users for playing two games simultaneously.

[KCZT12] is based on an old style Liquid Crystal Display (LCD) screen which can display clear image only when line of sight is perpendicular to the screen or in a range of field of angle. Taking advantage of this drawback, three POVs can be realized by displaying three different images in the same time. There are two POVs from each side of the screen and one POV from the perpendicular direction in front of the screen.

An immersion CAVE-like display approach for co-localized multi-user collaboration is proposed in [MBT11] and [MB11]. This approach combines technologies of active 3D glass (shutter glass) and passive 3D glass (anaglyph or polarised glass). Two users are displayed separately in two successive time intervals. When being displayed, user's space position is tracked in real time so that the views in each eye can be modified from the user's position. Four 2D views provide two 3D POVs to two users. Similar approach is adopted in a co-located multi-view table [LHS*14].

A co-located multi-view system which provides six users different POVs of a virtual environment is proposed in [KKB*11]. Three high frequency (360Hz) Digital Light Processing (DLP) projectors are for six users' left eyes. Each projector displays only one of the basic colours (red, green and blue) to one left eye with frequency of 60Hz. These three projectors can have 6 views. Adding another 3 projectors for six right eyes plus polarized glasses, totally 12 views, or we could say 6 3D POVs is realized.

As we discussed above, for a multi-view co-located multi-view support system, the importance is to create as many views as we could. From anaglyph and polarization approach, we obtain two views. From shutter glasses, the screen refresh rate defines how many separate views can be offered [MFP08]. All of them have to face their disadvantages: colour distortion for anaglyph, less brightness for polarization, and flicker for shutter glasses.

For screen-based technologies, developing multi-view effect means to create more parallax. The disadvantage is the limitation of viewing range and stable viewing angle.

2.2. Collaboration using multi-view

As we have discussed before, experts have their own point-of-view of DMU. These different POVs can have internal relationship. They are not isolated but are interacted on each other. On one hand, these relationships are restricted by different experts' individual requirements; on the other hand, they are links for collaboration among experts involved.

The visualizations of different point-of-view are usually described in two ways below:

- Two experts focus on the same scale of the DMU model, or the same resolution of DMU, which means the contents of these two point-of-views of DMU have the same level of data. E.g. both experts are focus on one part of a product. According to their different speciality, the POVs are different: one POV of FEA in specialty of structure analysis; one CFD POV in specialty of thermal analysis. If one change the geometry structure, both of their simulation analysis result will also change in real time. In this case, multi-view support system can play an important role for collaboration.
- Two experts are not on the same scale of the DMU. E.g. one is focuses on the architecture exterior design of a building and another is focus on electricity wiring design of a certain wall in this building. Second one's scale requires more detailed data than the first one. For exterior design, the response which is brought by changing electricity wiring is too weak and tiny. But they still have influence with each other because they are still in the same DMU. We can image that electricity wiring design will have effect on wall construction, wall construction will have effect on building structure, and building structure will finally have effect on building exterior design. In this case, multi-view support system seems not having great effect on these two experts.

There are a lot of multi-view display research and applications. From a technical perspective, they definitely display POVs to multiple users, but from a collaboration perspective, whether the task in the application has to be accomplished by two or more users is still a problem.

If two users are having less effect, or even no effect on the working contents, the multi-view displays will not have evident results in collaboration. Sometimes this may cause negative effect. There will be no difference if two users work separately. In some application, the reason why two users work collaboratively only seems to save one device for working.

So we describe the criteria of the collaborative effect that co-located multi-view support system brings to experts.

- **Interference**: co-located multi-view support system brings conflict between users. When multiple users have similar interactions with the displaying content, e.g.by pointing at one position on a screen, two users want to complete an interacting motion but they find physical conflicts. It is better to work separately instead of interferences. The multi-view contents have no relation but conflicts.
- **Unnecessary**: co-located multi-view support system brings nothing. If there is no relationship among multiple contents, users will have nothing difference with working on separated screens for each one. So it is unnecessary if the multi-view contents have no relation for collaboration.
- **Help**: co-located multi-view support system brings a lot. Multi-view contents have relations among them so that each view once gets changed, the other views will be updated in real time.

Next we will use our criteria to discuss collaborative effects of multi-view applications mentioned in 2.1.

One of the applications of [Mis09] and [NUH*10] is that two people are looking at a sentence which has been translated into two languages. Each user can understand the meaning when seeing the same screen. These multi-view devices really helped in this application case.

[MFP08] proposed some applications that may be used to multiple 2D view devices. One is to show several layers of Google Earth map with different geospatial information such as city name. Another application is to show a series of images that vary continuously in light density. Users can see different point-of-views standing in front of different angles with a display. These different point-of-views seem have influence inside, but not that obvious like DMU. These multi-view devices help collaboration or not depend on how users treat these series of images.

High frequency display like [TV15] and [Dis14] provided applications with which the two users play games separately on a same screen. From the point of collaboration, this is unnecessary because there is no difference if they use two screens.

[KCZT12] provided applications of seeing two pictures from different side of the screen and playing cards face-to-face with a judge in the middle. These multi-views of image displaying have no relations among them. For card games, it depends on which kind of games. If the game cannot be separated into several screens, the multi-view display will be strongly help to collaboration.

In the virtual assembly chain application [MBT11], two users collaborate to define the position of a seat by taking charge of different tasks to help each other. This multi-view system really helped the collaboration. However, in this team work application, users should have the same knowledge and speciality of assembly. Experts' professional domains are fixed.

One application of [LHS*14] is to manipulate pictures separately and to share pictures in a specific zone on the screen. From the point of collaboration, this application can be totally done on two screens because there are no relationship among the pictures they choose, it is unnecessary to have pictures manipulated co-located. Another application is to annotate roads on a map to generate a path. Two users can see two maps of the same region in different large and with different information. One with city roads details while the other with altitude level map. In this application, multi-view of different maps is really helping the collaboration between two kinds of users. Moreover, due to the interaction of both users' hands and the screen, an interference problem cannot be ignored.

A co-located multi-view system [KKB*11] with six views, has been applied to see and to manipulate a single model. If this approach can be applied to display six DMU point-of-views, this multi-view device will definitely help multiple users' collaboration.

As we discussed above, for real time collaboration, multi-view support system not only enables different users to share a display device, more importantly, its content and application have a strong requirement of information relation. Unlike a lot of applications that can actually be done separately, project review is a task that experts must work together with strong collaboration. This more practical application of DMU in industrial product and architecture design has more demand of multi-view support system.

2.3. Multi-interaction

To realize a multi-interaction CHI, many works have been done by extending the existing single interaction to a multiple way. Since touchpad has been a widely used CHI device for single interaction, each touchpad gives the user a personal scene to interact with vision and certain gestures. A lot of multi-interaction approaches developed a group scene, with which users can work together on it, to replace the remaining personal scenes of all the related devices. [HHL*07, GPH*11, ZBC*14, MLPvdH14, SKV14] are extending personal touchpads to an extra group scene or develop a new touchpad into a multi-user device, switchable from personal scene to group scene. This approach develops a device with a group scene to allow more users to work together and can still keep the user independence just like working on a touchpad. However, the metaphor of interaction is also as the former single touchpad, not varying according to different users.

[VB04] presents a CHI for different kinds of users differed in the distance away from a screen. For each of the four users in front of a gesture controlled screen, the CHI system has a special way of interaction. Not disturbing other users, this CHI can help four users interact with the content at the same time. This is a good example for giving different interaction strategies to different users with certain characters. However, if the users could choose their own way to interact, that will be much more ergonomic.

[SBL*07] and [MBT11] provide two users a CAVE based immersion environment, especially with gesture manipulation device, speech recognition device and haptic input device to interact with virtual models in multimodal mode. For different events of manipulation, users can generate a mixed rendering and multimodal feedback, which is useful in complex virtual scenes such as virtual assembly. This is a good example of multi-interaction devices utilization in virtual reality immersive environment.

[SGH*12, GWB04, WPS11] provide special working medium such as a stick or a ring to interact with the virtual object. Meanwhile special metaphors for interaction and a set of interaction principles are defined in a proper way. This might be equivalent to the creation of new device and redefinition the metaphor for the novel device, which gives the users a certain amount of freedom.

[BCC*08] lets users to choose methods to select an object. For example, a user may select an object if he/she holds their hand for more than a specific period, or if they make a rapid poking motion at the object. This approach allows user to define the interaction metaphor according to the user's willing, which is really helpful for our multi-interaction platform.

As we discussed, the multi-interaction of this CHI system should be multiple not only in using different device, but give users the freedom of define the interaction metaphor as much as possible.

3. Proposing appropriate solutions

We proposed several solutions for our estimated system. The simplest solution is with traditional VR visualisation technology, i.e., Anaglyph and Polarization. One POV of original geometry and one POV of aerodynamics CFD analysis result of an automobile DMU can be displayed on the screen and be separated by glasses. The glasses are formed by two original anaglyph or polarization lenses from one side.

If we superimpose two kinds of glasses, four POVs appear. Obviously the disadvantages of the two devices appear at the same time, i.e., the colour distortion due to Anaglyph and the less brightness due to polarized glasses.

We also proposed another two-view solution using a collaborative polarized table. Users can be provided 3D scenes in two directions. E.g. if one virtual wall is displaying vertically on the screen, each user standing physically at one side of the table can only see one side of the wall that faces him.

Besides multi POVs devices, we proposed an improvement of current device of Holografika [BFA*05] with advanced naked eye 3D displaying technology. It has over 30 laser projectors behind the screen. We are looking for a solution with Holografika to project multi-view contents to several users.

For multi-interaction, according to our current device, we propose a method utilizing Kinect in front of a certain screen. Kinect could identify several user and we could define ourselves that the same gesture of different users would react differently.

As the multi-view visualization system for DMU and multi-interaction are two parts of our whole collaborative DMU CHI. Therefore multi-view support system and multi-interaction can be modules of the entire collaborative platform. With the development of the multi-view and multi-interaction support system, these modules are of substitutability.

4. Conclusion and future work

This article describes digital mock-up's property of multi-representation. DMU contains all the product information during product life cycle in concurrent engineering. Domain-oriented experts have different POVs of DMU so they have problems of collaboration through several professional fields. Thus, a multi-view visualization and multi-interaction system for DMU's collaborative environment is proposed, on the scope of improving the interoperability among different experts.

For multi-view visualization, many main approaches and their applications have been discussed. Each approach has its apparent advantage and drawback and there is still room for improvement. However, most of the multi-view application has little effect on multiple users' collaboration. Many multi-interaction technologies have been discussed on both device level and metaphor level. Both levels of multiple interactions are necessary for our ideal system.

We have proposed multi-view support systems progressively using anaglyph and polarization, 3D table and Holografika. We also proposed a Kinect solution for multi-interaction.

Multi-view and multi-interaction support system is considered as part of the entire DMU CHI in collaboration. In the future work, a prototype of proposed multi-view and multi-modal interaction approaches will be developed. Each expert has its own style to interact with DMU, then to obtain the diverse response and finally to be displayed by multi-view support system. A multi-input and multi-output platform for working with DMU more collaboratively will be realized.

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