Research Article

Product Design Review in a Virtual Reality Environment

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Abstract
The aim of this research is the product design review in a virtual reality environment. The design activities consist of the usage or not of the haptic arm force-feedback combined or not with 3D stereoscopic display through basic sensors. The movements of design activities were evaluated by the low basic sensors application consisting of docking, duration, and instability sensor. The use case was thus organized around a barrel cam mechanism design which it has a single rotation motion but a complex cam 3D trajectory. We are specifically concerned by activities involved at design stage or at manufacturing preparation stage and we will have tuning design parameters to ensure that the mechanism is working well. We have implemented the experiment on four environments including either stereoscopy or haptic force-feedback device were used to establish comparisons respect to this research.

Keywords: Review, Product design, Virtual reality environment

1 Introduction

The current international competition, with the trends toward shorter development times to market requires challenging the keystones of product design [1] and innovation. New and innovative product development which uses the advance manufacturing technologies [2] is a process that requires resource investment and also involves collaboration between various experts including mechanical engineers, industrial designer, manufacturing engineers, marketing, etc. Product is developed to match a market demand to apply technological research through design, prototype tools, and manufacturing preparation of the innovative product [3]. Especially, the engineering design process is usually split into the following stages: ideation, conceptualization, feasibility assessment, design requirements, preliminary design, detailed design, production planning, tool design, and manufacturing [4]. We are interested in contributing to the design process for the automotive and aerospace industries.

Therefore, designers and engineers must find new tools or advanced technologies. The integrated CAD/CAE/CAM systems are modern technologies [5] which have been widely used for the complex manufacturing industry in the past five decades. CAD technology is widely popular to increase the productivity of designers, and manufacturing experts, improving the quality of design [6].

In addition, it improves communications through documentation, and creates a common database for manufacturing [7] enhancing collaboration. CAD

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technology is mainly used for detailed engineering of 3D models and/or 2D drawings of physical components, but it is also used throughout the engineering process from conceptual design and layout of products, through strength and dynamic analysis of assemblies to define manufacturing methods of components.

Notwithstanding CAD great development, CAD technology has limitations such as for complex design, collision detections, kinematics joint constraints, and advance dynamic simulation. It is an assumption that Virtual Reality (VR) could support to overpass these limitations because of its high potential for 3D visualization and interaction [8]. VR should support the manufacturing design and simulation as well. Currently, VR is demonstrated within professional applications for design engineers and manufacturing experts. VR technology can be referred as immersive multimedia or computer-simulated reality, it replicates an environment that simulates a physical real world or an imagined world [9], allowing the user to interact with this world. Virtual reality artificially creates, sensory experiences, which can include vision, hearing, touch, smell and why not taste.

Most up-to-date VR world was displayed either on a computer screen or with stereoscopic displays [10]. Some VR simulations include additional sensory information and focus on real sound via speakers or headphones targeted towards VR users. Some advanced haptic systems provide tactile force feedback [11], generally widely demonstrated within medical, gaming industrial, and military applications. Furthermore, virtual reality covers remote communication environments which provide virtual presence of distant users. The concepts of telepresence and telexistence introduced via VR, Virtual Artifact (VA) either driven by standard input devices such as a keyboard and mouse [12], or through more recent devices such as wired gloves or omnidirectional treadmills. The simulated environment is similar to the real world in order to create a lifelike experience. But simulations for pilot or combat training can differ significantly from reality [13]. There are a lot of VR environments different design and manufacturing tasks. VR environment selection still remains highly task dependent [14].

1.1 *Barrel cam mechanism*

An early cam was built into hellenistic water-driven automata from the 3rd century BC [15]. The cam and camshaft appeared in European mechanisms from the 14th century [16]. Cam mechanism was still used in automotive production because they still provide sharper manufacturing reproduction than numerical commands [8]. The cam trajectory itself is usually a 3D curve not really complex but hard to design and to optimize on 2D displays with usual CAD systems [17]. Here a barrel cam (Cylindrical cam) is designed and checked by simulation before it is produced. It is a component of a manufacturing process selected as a normal complexity use case but its design is not simple to finalize. Any efficient support to this design activity is welcome for industrial practice.

The barrel cam has a follower riding on a cylinder surface. In the most common type, the follower rides in a groove cut into the surface of a cylinder. These cams are principally used to convert rotational motion to linear motion parallel to the rotational axis of the cylinder. It automates the driving law of a manufacturing tool. A cylinder may have several grooves cut into the surface and thus it drives several followers. Barrel cams can provide motions that involve more than a single rotation of the cylinder and generally provides positive positioning, removing the need for a spring or other provision to keep the follower in contact with the control surface. To work well, correct dimensions and tolerances must be fixed. Specifically, a risk of blocking motion is possible in some specific area of the groove cut depending on the curvature and often inflexions of the groove. Figure 1 shows such a cam system designed within the CAD system (SolidWorksTM software) by engineers and designers. The system remains simple with indeed a single degree of freedom. But the 3D intrinsic nature of the groove cut makes the overall motion not so easy to anticipate on a cognitive point of view. The top figures of Figure 1 highlights the risky area where the motion can be blocked.

Mechanism simulation is the process of creating and analysis a digital prototype of a mechanism model to predict its performance in the real world. It is used by engineers to understand whether, and under what conditions. A part could fail and what loads it withstands. The mechanism simulation is a crucial step in the design process. The increasing variety product complexity increases requirements in terms of quality within a usual cost savings constraint.

Figure 1: The barrel cam modelled in a conventional CAD system.

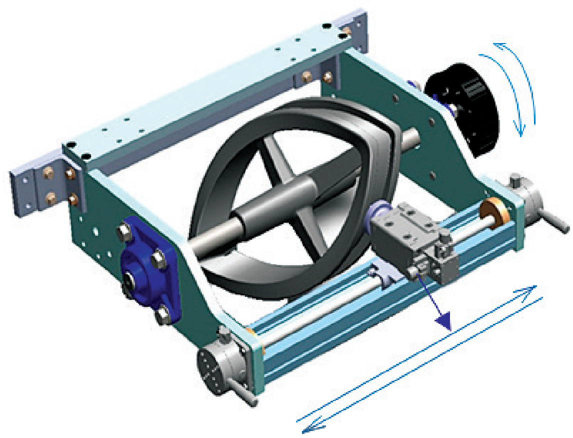

Figure 2: The overall barrel cam system to be included in the VR environment and movement direction.

The design of such a mechanism must assess its correct behaviour. Automatic mechanism analysis will usually fail here because too many potential contacts should create fake hyper static positions: the model tolerance is too close from the real tolerance. CAD system has insufficient potential for advanced dynamic simulation and connection with interaction device. Here it cannot be claimed that mechanism models could not be created but if it exists the modelling effort for designer is more complex than the expected result and such analysis will not be performed in most cases. Complex mechanism design, kinematics and performance optimization expect both dynamics solid mechanisms and deformation simulation (usually through the Finite Element Method (FEM)). Simulation is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system works. By changing variables in the simulation, predictions are made about the behaviour of the system [18]. It is a tool to investigate the virtual behaviour of the system under study.

1.2 *Research methodology*

If traditional mechanism analysis does not provide efficient simulation for designers, it becomes interesting to test if the depth dimension of 3D visualization plus interaction device operation with force feedback or non-force feedback lets better anticipate the corresponding behaviour. The main assumption is that potential blocking situations cause may be understood just by visualizing the 3D contacts when it occurs. If the engineer visualizes properly the current contact configurations he will directly perceive the main design parameters without complex simulation.

The virtual environment can integrate basic contact simulation but it will remain insufficient to check the critical position where motion is blocked. The integration of basic mechanics enables valid motions, as rotation, sliding (with some collision detections and kinematics joint constraints). We thus need to get the barrel cam mechanism model as presented in Figure 2 within the virtual reality environment. The CAD part shapes can be transferred and visualized in the virtual environment quite easily.

For the experiment, we focus on the good behavior when playing with a single degree of freedom, indeed the rotation, of the barrel. The designer is supposed to check any problem of the barrel cam mechanism blocking during this motion.

2 Expected added Value of VR for Designers

2.1 *Expected impact on design*

It is assumed that Virtual Reality (VR) has a great potential to help designers and engineers because it gives access to a product mock-up during its development and thus opens new simulation methods. It should offer a rapid loop between product model edition and simulations. Especially, business operations are highly competitive in terms of performance and cost for the product. Direct and rapid 3D model edition avoids the ancient engineering drawing standard and its complex consequences for many departments when updates are expected. Product development cost is increased by every defect in the design process. In the meantime, VR technology should support anticipation of future product lifecycle steps. It is expected to save cost by minimizing the time for design, simulation and testing loop.

Even with a large manufacturing experience we still find machines or products that cannot be processed. Therefore, design must be improved to ensure machines and final goods to work properly. To ensure good final behaviour engineers usually create prototypes which can be physic prototype or virtual reality prototype.

Currently, physical prototypes are viewed has highly expensive while virtual reality prototype are promising more potential and superior performance [19]. Despite designers, engineers, and manufacturing experts already experienced CAD/CAE/CAM technologies for manufacturing design in many industries, these CAD systems remain limited as well. Especially, most designers and engineers are using CAD system to assist the creation, the modification, the analysis, or the optimization of design and to create a database for manufacturing [20]. Therefore, limitations of CAD/CAE/CAM technologies make virtual reality technologies (virtual reality prototype) really attractive. Designers and engineers, expect new methods where VR technology is part of the solution. But it remains a lack of knowledge about efficient application of VR.

2.2 *Virtual reality environment expectation*

CAD systems are not appropriate for every design and simulation activities. We expect new opportunities from the capabilities, potentials, and performance of VR technology which can be extended as "Collaborative Virtual Environment Software". The main issue for the barrel cam case study is to analyze potential blocking positions when rotating the barrel. Here it is proposed before production, to check mechanism dimension with virtual reality environments.

As manufacturing companies pursue higher quality products, they spend much of their effort monitoring and controlling variation. Dimensional variation in production parts accumulate or stack up statistically, and propagate through kinematic joints, causing critical feature of the final product. Such dimension variations can cause expensive issues during simulation, requiring extensive rework or scrapped parts, and it can also cause unsatisfactory performance of the finished product, drastically increasing warranty cost and creating unsatisfied customers.

We expect to implement our case study within a virtual reality environment so that our research assumptions may be validated at the low basic sensor level.

3 Preparation of the Virtual Reality Environments

Designers, engineers, and manufacturing experts use 3D geometric models created in CAD systems. A translation of CAD model to VR model is thus, once again the initial process for working on virtual reality environment system. The 3D model was created within SolidWorksTM software which exports models into file formats such as STL file that we converted in OBJ file. The main reason to use OBJ file format is to get a good level of compression; it is also available for import inside most virtual reality system. In addition, for the barrel cam mechanism simulation, the virtual reality environment system expects the definition of kinematic joints [21]. Transferring 3D geometry of parts is not enough [22]. For this new use-case, kinematics constraints were rebuilt from scratch directly in the virtual reality environment. Therefore, it is just considered that each part is represented by a single polyhedron in the virtual reality [23] environment system leaded by pre-defined kinematic joints.

3.1 *Import 3D model files into CVE Viewer module*

The barrel cam mechanism consists of five bodies: 1) the machine structure, 2) the bearing housings, 3) the barrel cam, 4) the slider element, and 5) the slide bar. All elements were imported and exported in OBJ (OBJ, the file format is open and has been adopted by other 3D graphics application vendors) data formats from SolidWorksTM. The OBJ file format is directly imported into the CVE Viewer module and becomes a Scene Imported File as shown in Figure 3.

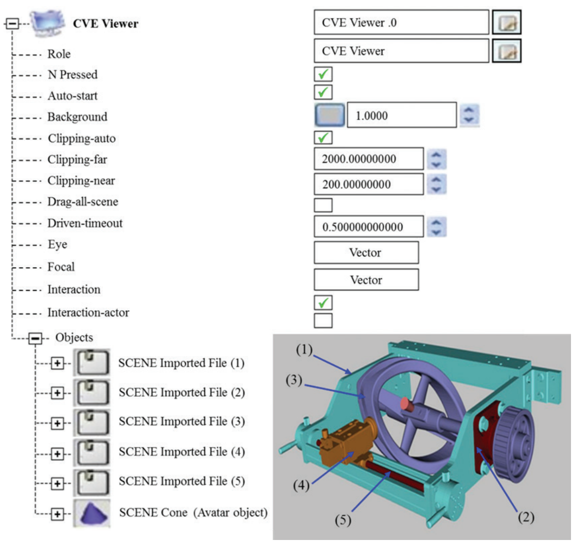

Figure 3: The 3D models imported into CVE and creates the scene.

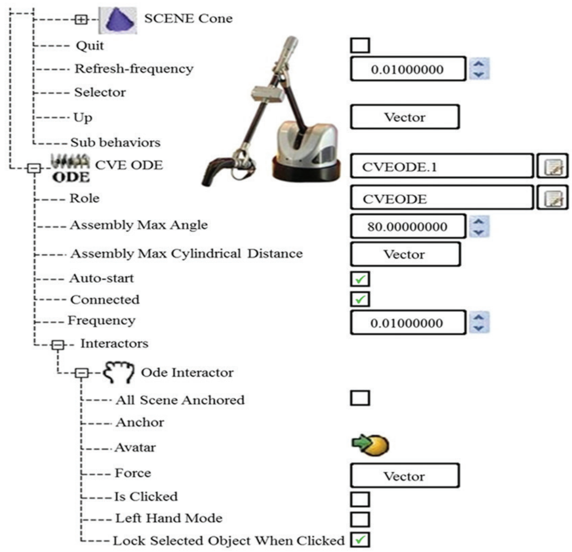

Figure 4: Avatar links human seesight perception to a haptic arm device by CVE ODE.

An avatar of the hand is created: we use a simple cone shape. The position and behaviour of this avatar will be linked to the user gesture (through the haptic arm device). The distance between the projection 2D wall screen and the interaction device (haptic arm) has been set at 2 meters. We do not use here head-tracking system. The cone is thus a remote representation of the hand. Background color and objects colors were also fixed directly in the viewer since color information was lost when exporting into the STL file format for our system [24]. Colors seem important to make a good distinction of parts but we did not make variation of color distribution to measure a potential impact on performance.

3.2 *Kinematic joint parameter setting functions on CVE ODE module*

Here again, we used CVE VR modeller. It enables rapid connection of various modules. The viewer is one of these modules. The CVE ODE module is another one in charge of real time object dynamics simulation [25]. It uses the Object Dynamic Engine developed by Russel Smith.

Figure 4, which shows the CVE ODE module is an agent with two main functions: it is in charge of collision detection but it was extended to rigid body kinematics [26]. The collision detection engine needs the 3D model shape of each body. At each time step, it figures out which bodies touch each other and passes the resulting contact point information to the dynamic engine. It was up to us to model the kinematic joints between the 5 bodies. The joint geometry and parameter setting should only be called after the joint has been attached to bodies, and those bodies must have been correctly positioned, otherwise the joint may not be initialized correctly. For the barrel cam system the joints, types ODE Fix, ODE Hinge, and ODE Slider were used.

3.3 *Avatar connection with the interaction device*

An avatar is used to provide a visual feedback of the position of the interactor within the virtual space. The haptic arm device is the Virtuose 6D from Haption company. The avatar is a cone replicates the motions of the haptic hand tasked via the haptic arm device [27].

The haptic arm has a button which is used to create a selection/deselection event. When the cone intersects a body of the barrel cam, a selection event creates a virtual spring between the selected object and the cone. The spring is a generalized spring which acts on both translations and rotations. The spring stiffness parameters creates a scaled effort which is both a force

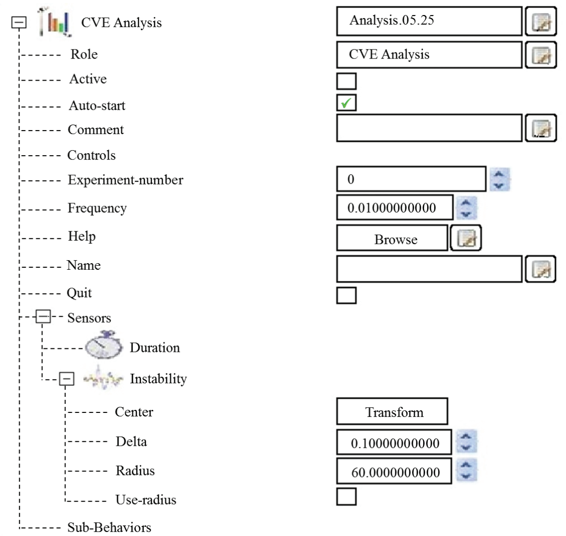

Figure 5: Two basic sensors (Duration and Instability sensors) have been applied for the barrel cam mechanism simulation.

and a torque. It replicates a simulated force feedback (currently there is no damping behavior).

3.4 *Basic sensors*

The VR model checks interaction with collision detection and kinematics joint constraints to achieve a design analysis: it should help to fix dimensions to avoid blocking cases. Three objective basic criteria are observed: 1) The duration of the task: the VR environment will be relevant as soon as it help saving time, but the duration of the simulation is also a criteria showing that the manipulation is easy for the user, 2) the gesture instability which highlights some ergonomic and tiredness issues and, 3) the completion of the task was measured by a docking quality. Here we expect that the user identify the correct dimensions for the barrel cam. Figure 5 shows the CVE configuration including the two sensors in the CVE analysis module which automate the observation. During the experimentation several barrel cam dimensions will be presented to the user and the user will have to check if there is a blocking point or not and why. A mark providing the number of good identifications over the overall number of checked configurations will be used as an objective completion criteria.

The instability sensor intends to measure the evolution of a position during a laps of time. The position of two points (point 1 and 2) in a frame defined by a transformation matrix is permanently analyzed.

4 Experimentation Description

4.1 *Description of the participants*

The participants to the experiment are PhD students and graduate students of G-SCOP laboratory and other close laboratories. Thirty participants participated to this experiment. They have engineering design knowledge but most of them never used this virtual reality environment system or they never manipulated virtual reality environment equipment at all. A few ones already experienced once such equipment and it will be for them a second experience (they participated to the previous experience in this research program). It has been elucidated to the participants, before the experiment starts, how to employ the interaction devices. They all test the selection, the rotation, movement, and simulation procedure to be performed in the experiments before the capitalized session. The participants were conducted in a comfortable stand postures by standing about 2 meters away from the screen.

4.2 *Experimentation protocol*

The thirty participants are invited to assess mechanism blocking by the use of CVE tools. The haptic arm Virtuose 6D35-45 is the device which offers force-feedback on all 6 degrees of freedom together with a large workspace. It is the main equipment with the stereoscopic display leading four environment as follows:

1. The first environment consists of the haptic arm without force-feedback + non-stereoscopy + on the 2D wall screen.
2. The second environment consists of the haptic arm without force-feedback + stereoscopy + on the 3D wall screen.
3. The third environment consists of the haptic arm with force-feedback + non-stereoscopy + 2D wall screen.
4. The fourth environment consists of the haptic arm with force-feedback + stereoscopy + on the 3D wall screen.

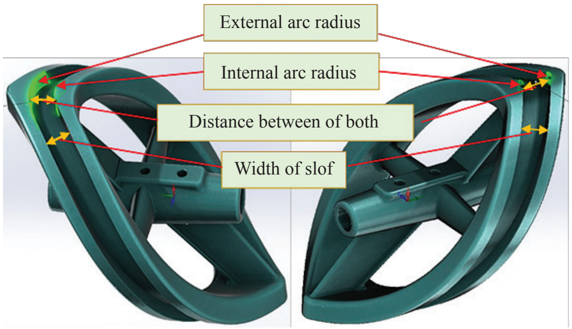

Figure 6: The specific features dimension that affect for the rotate simulation, left and right pictures are two different versions.

5 Analysis of Basic Sensors by the Use of Barrel Cam Mechanism Simulation

5.1 *Finding appropriate dimensions by rotating simulation on the barrel cam*

The goal for the "designer" involved in this experiment, is to find the appropriate dimension of internal and external arc radius for the barrel cam. Within a good machinery parts design, the designer or engineer must identify the accurate dimensions and tolerancing to avoid any damage or crash, and of course to allow the cam system to work properly.

The slot geometry in this area is complex and defined by several parameters which alltogether determine the positive or negative gap between the slot and the follower cylinder. A bad set of values may lead to unwanted blocking behavior for the mechanism, instead of the expected fluidity of movement when the cylinder crosses this area.

Figure 6 is the main dimensions that affect the barrel cam behavior include the following: internal arc radius, external arc radius, width of slot and distance between the two arcs.

This experiment context aims to analyze and find the appropriate dimension of internal and external arc radius for the barrel cam design. The user is supposed to analyze the possibility for the barrel cam to rotate continuously without blocking or having other unwanted behavior. Simultanuously the balance and stability of manipulation is evaluated in the experiment by the use of basic sensors of the "Collaborative Virtual Environment Software". Factors affecting the expected movement for a barrel cam are the dimension of internal and external arc radius as well as the distance between the two arcs. A barrel cam model was created by using SolidWorkTM software where arc radius were created by the "fillet" command. Therefore, the distance between internal and external was related to the two arcs independently issued from the CAD fillet command. For the experiment, we considered the dimension of a barrel cam through six couple of radius values defining the distance between both arcs as shown in Table 1.

Table 1: The various dimensions that affect for a barrel cam rotation

Type	Internal Arc (Radius)	External Arc (Radius)	Width of Slot	Distance between Both Arcs
1	0 mm	0 mm	20 mm	24.00 mm
2	05 mm	25 mm	20 mm	20.17 mm
3	10 mm	30 mm	20 mm	20.98 mm
4	15 mm	35 mm	20 mm	20.98 mm
5	20 mm	40 mm	20 mm	20.92 mm
6	25 mm	45 mm	20 mm	20.39 mm

5.2 *Experimental results of the task duration for barrel cam 6 types*

In this section, the experimental results about the task duration for 30 participants and the four environments are reported. The reports of duration for the 6 types of barrel cam and for every environments is depending on the repetition of the task respect to the six configurations. The user analyzes the possibility for the barrel cam to rotate fluently or having other unwanted movement behaviour like friction or instability. These results are summarized from the table in appendix D and the average of all environments are shown in Table 2.

Table 2: Experimental results of the task duration for barrel cam 6 types

Environments	The Type of a Barrel Cam (Second)					
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Environment 1	2.262	2.174	2.233	2.127	2.216	2.071
Environment 2	2.143	2.327	2.473	2.126	2.308	2.302
Environment 3	2.158	2.348	2.227	2.160	2.424	2.159
Environment 4	2.176	2.375	2.276	2.199	2.327	2.165
Average	2.185	2.306	2.302	2.153	2.319	2.174

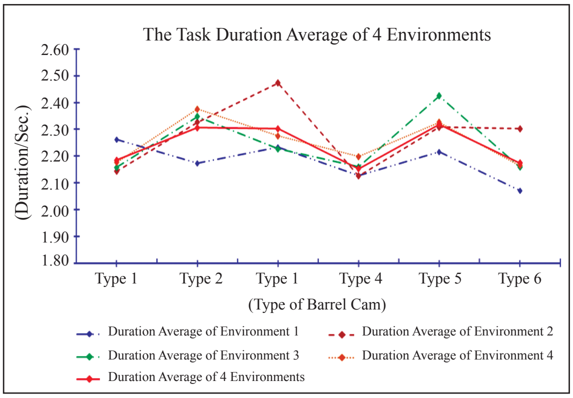

Figure 7: The task duration graph of barrel cam six types for the four experimental environments.

For better understanding, we had converted the task duration data from Table 2 into the graphics of Figure 7. It may be noted that repetitions do not decrease the task duration. No obvious explanation helps to understand this graph. We need to make a correlation between duration and the two main parameters, the slot distance, and the radius value, to get a deeper understanding.

Figure 7, the best results of the task duration are located under the red line (average values of all environments). Here, the first environment (Environment 1 consists of the haptic arm without force-feedback + non-stereoscopy + 2D wall screen) is the blue line which is the best result respect to task duration. This means that the use of a haptic arm without force-feedback and non-stereoscopy leads to quicker task. Furthermore, we want to find and analyze the various dimensions that affect a barrel cam rotation. Thus, the best dimension for the barrel cam design, according to time simulation criteria, seems to be the type 4 because the experiments durations are low whatever the environment step repetition and the product configuration.

5.3 *Experimental results of the gesture instability for 6 barrel cam types*

In this section, the experimental results of the gesture instability are reported for the 20 participants and the four environments. These measures are used to calculate the average values of every environments: the results are summarized in Table 3.

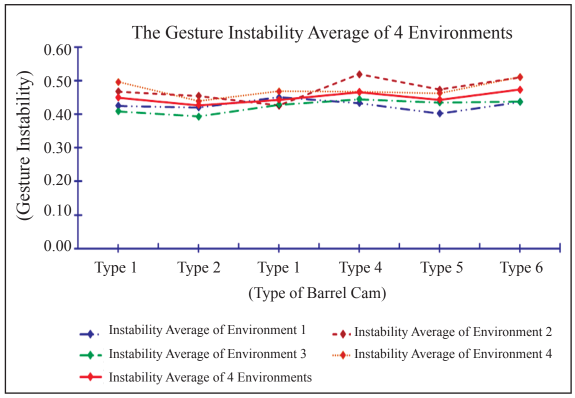

Figure 8: The gesture instability graph of barrel cam six types for the four experimental environments.

Table 3: Experimental results of the gesture instability for the 6 barrel cam types

Environments	**The Type of Barrel Cam (Second)**					
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 5**	**Type 6**
Environment 1	0.425	0.420	0.450	0.433	0.402	0.436
Environment 2	0.467	0.454	0.426	0.519	0.473	0.510
Environment 3	0.408	0.393	0.428	0.445	0.435	0.437
Environment 4	0.496	0.439	0.468	0.466	0.462	0.510
Average	0.449	0.426	0.443	0.466	0.443	0.473

From the Table 3 above, the gesture instability values of all the environments and every types of the barrel cam is not much different. For better understanding, we had converted the gesture instability values from Table 3 data into the graphics of Figure 8. It may be noted that repetitions do not decrease the gesture instability values. Then it seems that there is no obvious learning or training effect whatever is the environment. Nevertheless, the graph on Figure 8 describes our experimental results.

The best results are located under the red line (average values of all environments). Here, the third environment (The third environment consists of the haptic arm with force-feedback + non-stereoscopy + 2D wall screen) is the green line which seems to be the best result for the gesture instability. Furthermore, we want to find and analyze the various dimensions that affect a barrel cam rotation. It means that the value of the great gesture instability is under the average line. Thus, the perfect dimension for a barrel cam design is a barrel cam-type 4 because the several lines graph provides low gesture instability value: a low graph line means a lower gesture instability.

From the experimental results, we can choose the appropriate dimension of a barrel cam which is the fourth type. Again to ensure the accuracy for our experiment, we have assessed the 4 environments by use of barrel cam-type 4 and the same experiment with 20 participants.

5.4 *Analysis of the task duration results*

In this section, the experimental results about the task duration of every environments are reported. It reports the task duration for every environment depending on the repetition of the task respect to the ten configurations tested by every user (the participant twisted the roll axis of the haptic arm to rotate 180 degrees per time order equal to 1 configuration and we will count the twisted clockwise or counter clockwise). The duration usually decreases while repeating the task unless the 10th average value for environment 1 is over the average value. This was due to a specific measure point that should be removed from the raw results. Then we can analyse a kind of basic learning.

Anyhow the average duration from the Table 4 for each environment is very similar because the participant just twisted the roll axis of the haptic arm to rotate 180 degrees per time order which it was a short-term rotation and the task still remains simple. Anyhow, the best average duration is the lowest value which is reached with the fourth environment (The fourth environment consists of the haptic arm with force-feedback + stereoscopy + on the 3D wall screen). It confirms the experience from Chapter 4 and it seem, that haptics has a positive effect here. A good average duration is also reached with the third

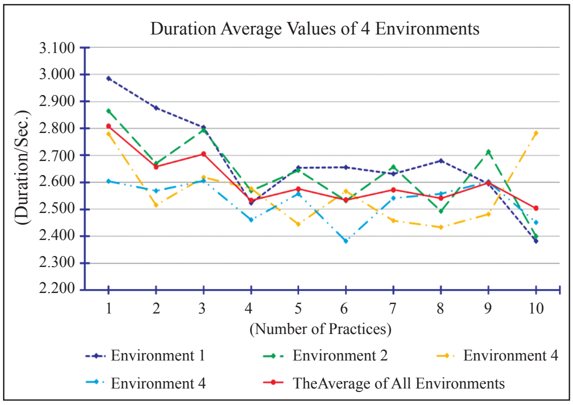

Figure 9: The graph of duration average values of the 4 environments.

environment (a haptic arm with force-feedback + non-stereoscopy + on the 2D wall screen). Then comes the environment 2 with an average duration of 2.634s. The second environment consists of the haptic arm without force-feedback + stereoscopy + on the 3D wall screen. And at last the first environment consisting of the haptic arm without force-feedback + non-stereoscopy + on the 2D wall screen) reaches the higher average duration. Table 4 was converted into Figure 9 for another highlight of the figures: the red line is the average value of all environments.

The best results are located under the red line (average values of all environments). If we consider that the average value of the sky blue line is the lowest one, the fourth environment is the best for this activity respect to the single duration criteria.

5.5 *Analysis of the gesture instability values*

In this section, the experimental results about the gesture instability are reported for the four

Table 4: The duration average values of four environments

Environments	Times Order Number (Second)										
	1	2	3	4	5	6	7	8	9	10	Average
Environment 1	2.985	2.876	2.803	2.524	2.655	2.656	2.631	2.680	2.594	2.381	2.678
Environment 2	2.864	2.670	2.794	2.569	2.644	2.532	2.657	2.493	2.713	2.400	2.634
Environment 3	2.780	2.515	2.619	2.577	2.445	2.567	2.458	2.434	2.482	2.783	2.566
Environment 4	2.605	2.568	2.606	2.462	2.558	2.382	2.542	2.557	2.602	2.451	2.533
Average	2.808	2.657	2.705	2.533	2.575	2.534	2.572	2.541	2.598	2.504	2.603

environments are used to calculate the average values of each environment: the results are summarized in Table 5.

Once again instability average value does not vary so much respect to each environment: the barrel cam mechanism simulation activity of our experiment lasts a very short time about 3 seconds. Nevertheless the more instable experience are obtained with environments 3 and 4 which both use the haptic arm with force feedback. The force feedback constraint the gesture resulting in non-expected gestures from the user. Here again, stereoscopy does not provide an obvious added value (environments 2 and 4 respectively compared to environments 1 and 3).

For better understanding, we had converted instability data from Table 5 into the graphics of Figure 10. It may be noted that repetitions do not decrease instability. Then it seems again that there is no obvious learning effect whatever is the environment.

Figure 10 above, provides the red line as the average values of every environments. The best instability values of the virtual reality environment is the lowest graph and it is under the average line (red line graph). Assessing results of instable values for the four environments, it appears that the environment is unstable under the average line. The two best environments following this analysis are the first environment (The haptic arm without force-feedback + non-stereoscopy + on the 2D wall screen), and the second environment (The second environment consists of the haptic arm without force-feedback + stereoscopy + on the 3D wall screen) which are the blue line and the green line graphs. Without force-feedback, the participant seems to find a simplest and more convenient control of movement direction of a haptic arm. To summarize briefly this assessment, the haptic arm without force-feedback is more stable than haptic arm with force-feedback. But for sure, we would like to assess the performance of virtual reality environment combining this result with other basic sensors.

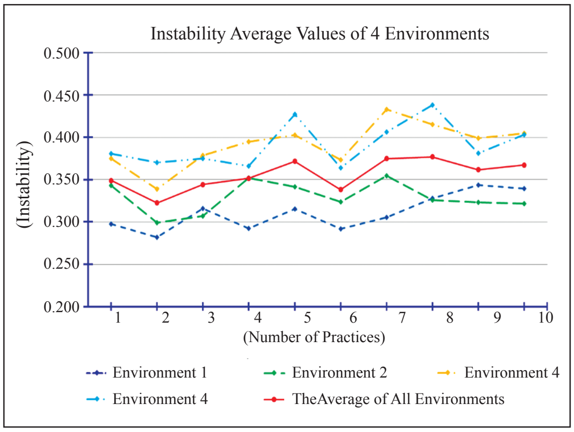

Figure 10: The graph of the gesture instability values for the 4 environments.

5.6 *Finding quality of VR environment by check blocking configurations*

In this context, we expect to assess the quality of the four virtual reality environments by the use of a barrel cam blocking model. A barrel cam was blocked by the geometric dimension and tolerrace are not correct. It can be verified by the use of haptic arm with force feedback as shown in Figure 11.

The participants must be conducted to achieve the objectives under the three main conditions of the question as follows:

1. Will you be able to recognize and feel when a barrel cam is blocked ?

2. Will you be able to see clearly the position of barrel cam when it was Blocked ?

Table 5: The gesture instability average values of four environments

Environments	Times Order Number (Second)										
	1	2	3	4	5	6	7	8	9	10	Average
Environment 1	0.297	0.282	0.316	0.292	0.316	0.292	0.305	0.328	0.343	0.339	0.311
Environment 2	0.343	0.299	0.307	0.352	0.341	0.324	0.354	0.326	0.323	0.321	0.329
Environment 3	0.375	0.339	0.378	0.395	0.403	0.373	0.433	0.415	0.399	0.405	0.392
Environment 4	0.381	0.370	0.375	0.366	0.427	0.364	0.406	0.438	0.381	0.403	0.391
Average	0.349	0.323	0.344	0.351	0.372	0.338	0.375	0.377	0.362	0.367	0.356

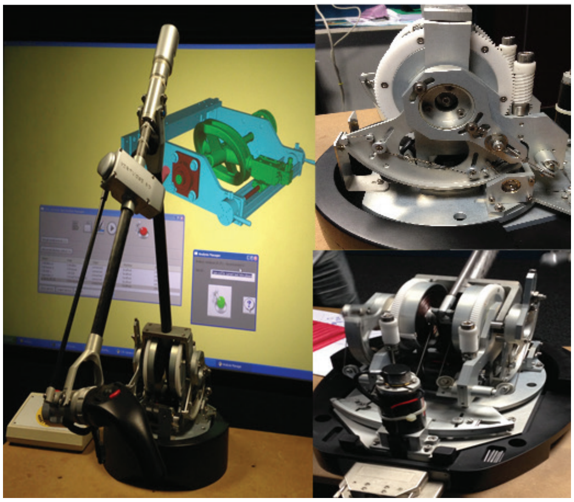

Figure 11: The haptic arm mechanism for verified a barrel cam blocking model.

3. Will you be able to understand why it was blocked ?

If an end user can answer correctly to these questions, then the VR environment will provide added value to the design task. This why we suggest to check this criteria as a quality assessment.

Conducting experiments in this respect, the participants attempted to rotate and to analyze the blocking issue of barrel cam by the use of 4 environments. The participants had to fill out the scores in the questions of the Table 6 when they had used all the four environments and complete the experiments. The status of scores, the characteristics of scores for this experiment consists of the following: Excellent = 4, Well = 3, Fairly = 2, and Inefficient = 1.

The scores of the 30 participants applied to the 4 environments for the blocking issue of the barrel cam was recorded and are shown in Table 6.

The quality of the environment is depending on the scores of the participants because we have no direct sensors to measure quality of virtual reality environments. The result seem very clear here. The best quality is reached with environment 4, then environment 3, 2 and the wrost is the environment 1. Both stereoscopy and haptic arm seem to improve quality. For this use case, environment 3 provides better quality than environment 2. We must conclude that for this case, haptic arm is more important than stereoscopy.

Table 6: The scores of the 30 participants by the used block model

The Quality of the Environments				
Participants	**Environment 1**	**Environment 2**	**Environment 3**	**Environment 4**
1	2	1	3	4
2	1	3	2	4
3	1	3	2	4
4	2	1	4	3
5	1	2	3	4
6	1	2	3	4
7	2	1	3	4
8	2	3	1	4
9	1	2	3	4
10	1	2	4	3
11	1	2	4	3
12	2	1	3	4
13	1	2	3	4
14	2	1	4	3
15	2	1	3	4
16	1	3	2	4
17	1	2	4	3
18	1	2	3	4
19	1	2	3	4
20	2	1	3	4
21	1	2	3	4
22	1	2	4	3
23	2	1	4	3
24	2	1	3	4
25	1	2	3	4
26	1	3	2	4
27	1	4	2	3
28	2	1	3	4
29	1	2	3	4
30	1	2	3	4
Minimum	1	1	1	3
Average	1.367	1.900	3.000	3.733
Maximum	2	4	4	4
STDEV	0.490	0.803	0.743	0.450

6 Conclusions

In order to conclude the experimental results about basic sensors as compared; the duration average of Table 4 and an instability average of Table 5 plus the quality environment average of Table 6 for every environments are combined and shown in Table 7.

Table 7: Experimental results of the basic sensors combined with the quality value

Environments	**Speed/Second**	**Stability**	**Quality**
Environment 1	0.373	3.215	1.367
Environment 2	0.380	3.040	1.900
Environment 3	0.390	2.551	3.000
Environment 4	0.395	2.558	3.733
Average	0.384	2.810	2.500

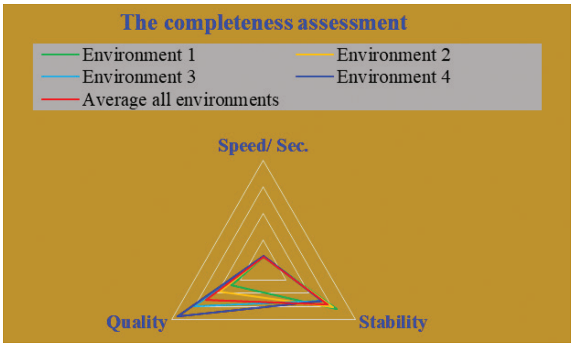

Figure 12: The spider graph of the completeness assessment.

For better understanding and comparison convenience, we convert experimental results of the basic sensor combined with the quality value data from Table 7 into the graphics as shown in Figure 12.

The spider graph shown in Figure 12, provides the red line graph as the average values of every environments. The best completeness assessment values of the virtual reality environment is outside the average line (red line graph). The graph is summarized respect to three main conclusions:

1. No speed influence, because the experiment activity remains very fast, no high difference can be perceive here.

2. Respect to stability, the first and second environments provide more stable gesture than the fourth and third environments.

3. Respect to quality, the fourth environments has the best quality value, the third environment is also a good quality environment. But the worst quality environment are the first and second environment.

Thus if the assessment is 3-folded (Speed/Stability/Quality) the criteria have contradictory influence, and the environment selection will be a compromise.

I would say finally that it is observed that the two basic sensors criteria are not discriminant, as differences between 4 environments respect to speed and stability are little. On the other hand, we speak of the main purpose of setting up this VR simulation, which is cam blocking detection by the user through VR manipulation. Then the main criterion to choose a VR environment for an intended purpose would be that it is the most efficient for the user, and in this context, the so-called quality criterion is clearly discriminant, showing the advantage of force feedback and stereoscopy.

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