Valkyrie Project: Flying Immersion in Virtual Reality

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***Abstract*—The aim of the paper was to explore a new approach for flight simulation in virtual reality and to study user's perception of virtual avatar embodiment. The exploratory research started with (i) the perception of wings on the body, and the natural movement that people do when flying. The results were used to (ii) create a model and a virtual environment in order to explore the extent of the virtual presence and virtual body ownership of the users. To get appropriate user feedback a questionnaire with 76 international participants was used. The results indicated that 78.6% imagine having wings on their shoulders and on their back. In addition to that, 57.3% move their arms as intuitive action to fly. Based on these results the model has to follow the flapping flight simulation in a way that wings would be attached to the shoulder. An angelic avatar was designed and a game-based story was used to justify the connection of moving hands and having wings on the shoulder. This provides an insight into the perception of wings and action of flying as felt by the user. The last experiment used questionnaires to assess the extent of immersion and presence of the users in the virtual environment. The results indicate that such a setting provides an immersive effect for flying in virtual reality.**

***Index Terms*—Wing Perception, Flight Perception, User Immersion, Virtual Reality, Flying**

I. INTRODUCTION

This study researches the use of virtual reality as an emergent technology to provide an immersive environment in which the user can perceive the flying. We aim to answer the following research questions:

1) How is the perception of wing ownership by humans?
2) What is the natural action that people do when they are asked to fly?
3) Can a model based on these findings provide the users with flying immersion?
4) Would the users pay to try such a system? If yes, how much?

The study primarily followed a user centred design approach [1] in the implementation phase in order to produce the most viable model before the final testing. Through this process, some additional findings and measurement which were related to haptic feedback will result in future studies, however, the last model is using a wing-shape made of hard paper with feathers attached to it.

II. RELATED WORK

A. Measuring Presence and Immersion and Games

The final questionnaire to measure immersion in this study consists of a mixture of questionnaires by M. Usoh et al. [2] and Witmer and Singer [3]. Marie-Laure Ryan [4] gathers a vast range of perspectives toward the immersion and interactivity in the virtual reality. The article ranks role-playing games as the highest when it comes to interactivity and second when it comes to immersion. Virtual reality technology should be integrated into games so that it can remain relevant in this fast-paced trend [5]. The design approach and the taken development process is highly dependent on its goals. The user's expectation of the game and environment is the first and most important factor in producing immersion in virtual reality and 3D computer games [6]. We also see how user centred design approaches can help us achieve this goal [7].

B. Flying and Wings

In [8], OptiTrack and fundamental physics of flying were used to implement a realistic approach towards a natural bouncing movement rather than gliding. Despite immersive flying results, the users did not feel virtual body ownership. A simple reason for that was using a bat as the avatar. Another point which we tried to note and adjust in comparison to this study was to create an immersive environment which would be interactive. Noting the pyramid of presence and immersion [9] [10], we must always make sure that without underlying factors, we may not achieve higher level results. Regardless, the implementation of tools and processes in our study are pretty similar to theirs. However, our main difference is that we took the user-centered approach [1] to design the system and within those feedback loops and design researches, we tried to ensure that the final product is as usable and acceptable as possible by our target group.

M. Egeberg et al. [10] is focusing specifically on the extension of the human body and various effects. They conclude that visuomotor feedback was required in order to establish agency and body ownership of the wings, and visuotactile feedback significantly enhanced body ownership of the wings, and agency according to questionnaire ratings. This study emphasizes the importance of the visual representation and its relevance for agency and body-ownership.

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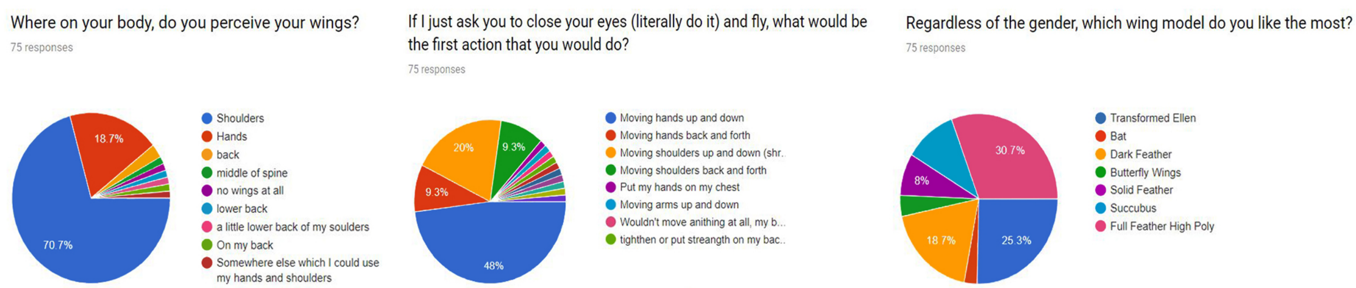


Fig. 1. Wing Location Attachment on the Body (left), Bodily Movement Conductive to Simulating Flight (middle), Favorite Wing Model (right).

III. Research

This part of the study tried to answer the following questions:

1) When it comes to an extended winged body (avatar) for humans, where on their body do they perceive their wings? Or do they even imagine flying with wings?
2) When asked to fly, what is the natural action that they do? In other words, how do they perceive themselves flying?
3) Among the variety of wings presented visually, which one do you prefer?
4) If there was a product in an amusement park/arcade in which you could experience immersive flying, how much would you pay for it?

The questions in this study are related to the respective research questions. The first and second are measuring the perception directly. The third will provide a base for the avatar. The fourth will do the initial evaluation of expectation and price range for the major questionnaire in the final experiment.

A. Research Results

In this research, we learned that 78.6% of the participants imagine wings to be located on their shoulders and back (in the area between spine until shoulders - butterfly mode), while only 18.7% of the participants expect their wings on their arms (bird mode). The rest 2.6% preferred to fly without wings (superman mode). Thus, we placed the wings on the shoulder for our avatar implementation (cf. Fig. 1).

Regarding the movement of flight, the following results were gathered. The majority of the population was moving their hands and arms up and down (48%). In addition to that, 9.3% of the population was moving their hands and arms back and forth. The second largest group was the one which was moving their shoulders up and down and consisted of 20% of the population. They are followed by 9.3% who move their shoulders back and forth. The rest were single ones who did scapular contraction and protraction or simply wanted to fly like Superman. Thus, we used the arm movement for our VR game as the input for flight (cf. Fig. 1).

Considering the wing model, the sum of 74.7% of the population liked feathery wings. Among them, 44% liked the dark color and 30.7% liked the white color. It was followed by succubus, solid, butterfly, and bat with 10.7%, 8%, 4%, and 2.7% respectively. Thus, we used the dark feather model for our angelic model implementation (cf. Fig. 1).

The participants were eager to pay 17.8 euro on average to try such a game in an amusement park or arcade. The participants were 50.7% male and 48% female (the rest preferred not to say). The population included 73 VR enthusiasts who were from Germany, Iran, India, Italy, France, Netherlands, Colombia, Romania, Bosnia and Herzegovina, and Korea. Thus, we did our best to ensure the representativenes of the population.

IV. Haptic Studies

This section presents the haptic research in order to create the final model. The research focused on three ideas (cf. Table I) and found that paper wings with feathers attached to it are the most acceptable model.

TABLE I
Tested Haptic Models Conclusion

Model	Accept	Major Reason
Small Actuator on the Skin	No	Pull was felt on the surface rather than muscle
Bands on the Shoulder	No	Limiting movement, and bands were being dislocated towards the neck during play
Paper Wings with feathers	Yes	Air drag force and feathers aligned with natural movement

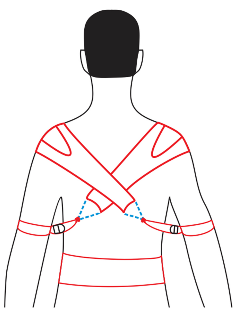
The small actuator model was imitated using bands and stickers on the skin on 3 participants and none of the participants accepted that. The data from the measurements can be seen in Table II.

The bands attached to the shoulder and being pulled by arm movement worked well in isolation (7/8 accepted it) when the participants were only imagining themselves flying. The model in Fig. 2 is a result of seven iterations of user feedback including 4-5 users in each iteration. Later, it was tested in the virtual environment. Since the bands were sliding towards the neck with movements, and it was limiting the user in general, none of the 8 participants accepted the model. The data from the measurements can be seen in Fig. 2.

The paper wings model focused on providing the haptic on the arms rather than the back and 6 out of 6 initial participants accepted the model. Thus, this model was used for the final research. Be referred to Fig. 3.

TABLE II
SCAPULAR CONTRACTION AND PROTRACTION DIFFERENCES

Configuration	**Scapular Protraction in pixels**	**Scapular Contraction in pixels**	**Difference in percentage**
Lying closed arms	486	449	8.2
Lying 45 degree open	466	455	2.4
Lying 90 degree open	445	417	6.7
Lying 135 degree open	451	443	1.8
Lying 180 degree open	451	447	0.9
Standing closed arms	515	461	11.7
Standing 45 degree open	471	438	7.5
Standing 90 degree open	488	447	9.1
Standing 135 degree open	514	479	7.3
Standing 180 degree open	486	449	8.2



Gender	Test	Force	Height	Weight
M	Ortho	40N	180cm	63kg
M	Diag	30N	180cm	63kg
M	Ortho	46.72N	173cm	54kg
F	Ortho	34.16N	175cm	78kg

Fig. 2. The Final Physical Model for Haptic Feedback

V. IMPLEMENTATION AND EXPERIMENT

A. Implementation

The implementation was done in Unity using the C# programming language. The wing models were created in 3Ds-Max and were imported into Unity. The 3D Game Kit of the Unity Asset store was used to provide the base environment for the game. In addition to that, a story was developed so that the users would have the basics of immersion served. OptiTrack was used to track wing game objects. The movement of those objects was used to trigger fly function and flying animation inside the game.

The wing animation curves were adjusted to reflect a natural flapping movement rather than a linear movement. The fly function would immediately bounce the character upward and forward. The amount of bouncing was exposed as a public variable to be adjusted, however, during the experiment, it was fixed so that we make sure it does not interfere with other factors.

The orientation of the character is based on the direction of the HMD (Head Mounted Device) which is the direction the player looks at. The value of the slerp (spherical linear interpolation) was adjusted to reflect the best user experience with the least chance of cybersickness. The final character in the environment can be seen from a third person perspective in Fig. 3.

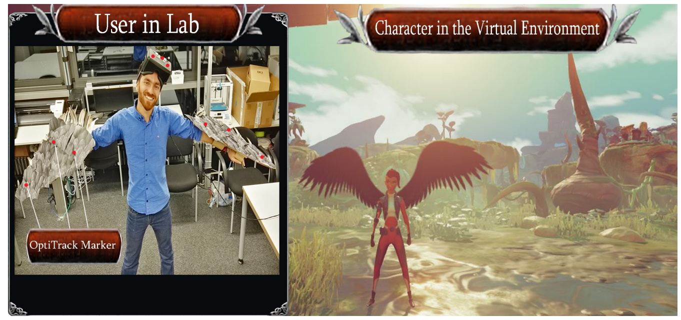


Fig. 3. Overlay of the Real and Virtual Environment

The system consists of three main parts, one PC, OptiTrack, and HMD Kit (Oculus Dev Kit2). Twelve OptiTrack cameras track the markers in the environment. Three markers are required on each object to make a rigid body. The data from the cameras are transmitted to the OptiTrack hub and then to the PC. Motiv software translates the data from OptiTrack cameras into coordinates and objects and sends it as a stream of data to Unity game engine running on the same PC. Unity gets the objects (wings and HMD) coordinates from Motiv and calls functions based on any change to the coordinates. Lastly, Unity sends the output to the monitor and HMD.

B. Experiment

The experiment was carried out in the EISLab at the University of Passau. The area covered by OptiTrack was almost 10 square meters, however, due to the connecting cables of the HMD, only 6 square meters were used. Since the participants were supposed to simply flap in place, the area was pretty abundant.

The story of the game was as follows: "You are in the year 2100 and you have landed on an alien planet. You have been enhanced with a set of wings on your shoulder which takes the order to flap from the movement of your hands. Your task is to explore the area, survive, and make it to the great portal".

The users were tested individually. The process started by telling the user the story of the game so that the atmosphere they see in VR and contradiction between moving arms and having wings on the shoulder would have some logical explanation in their mind. The environment contained enemies, poisonous waters which they must avoid, magical platforms which will be activated when stepped on, crystals which would be activated when passed through, and finally the great portal which they had to find and pass through to finish the game.

The first section of the questionnaire consists of 12 questions. The first 4 are taken from Slater et al. [2] and the next 6 are taken from Witmer et al. [3] and the next 2 are inclusive to this study. The eleventh question measures the wing ownership, and twelfth one measures the avatar embodiment. The questionnaire's reliability is tested using Cronbach's alpha (0.81) which is over an acceptable threshold for exploratory researches (0.7) [11]. The next section of the questionnaire included demographic questions, followed by two questions. First one asking about their experience of VR, and the second one asking about their eagerness to try out this system in an amusement park by the amount of money they would pay. The maximum amount was 30 euro.

In this study, 27 participants were students of the University of Passau aging between 18 to 34 years old. 59.3% of the population were male and 40.7% were female which shows a relatively balanced distribution of genders. From nationality perspective, the participants were from the following countries: Germany, France, Spain, Russia, Mexico, Iran. Two third of the participants had experienced virtual reality before. Thus, ensuring that the majority had some point of reference beforehand. One third had not experienced virtual reality beforehand, however, they stated that they were totally familiar with the technology. 85.2% indicated that they would pay up to 30 euro to play such a game in an amusement park or an arcade.

Conclusively, this experiment showed that the action of flapping flight can increase the user's presence in virtual reality games. In addition to that, we found that when it comes to flying, having adjustable flapping speed can become a positive factor in immersion. Another important lesson was to have gliding in parallel to flying which can be activated based on the user's movement. This is certainly another user-centred factor which must be taken into account. Based on the participant's direct feedback, it is advisable to have future studies in a CAVE environment with safety measures and also add walking to the game to compare the results.

VI. Conclusion and Discussion

This study specifically explored flying in virtual reality. The core idea was to discover the favourite embodiment form for flying. Since, to the best of our knowledge no study could be found to measure this perception and test it in VR, we had to do it through a series of implemented studies with accompanying questionnaires.

In the perception research, 76 participants attended who were VR enthusiasts. The results showed that 70.7'% perceive wings on the shoulder and 18.7% perceive it on the back. On the same research questionnaire, we also asked for the instinctive and natural movement associated with flying. The results indicated that 57.3% of people move their arms in order to fly (48% up and down, 9.3% back and forth).

The contradiction found in this study is the difference between the imaginary image of wings which are located on the back (shoulder), and the movement 'arms up and down' that is done by the majority of people as an instinctive action for flying. This contradiction is hard to reconcile from a design point of perspective, however, we tried to use the story as a tool to fill out this gap.

The study tried to explore haptic feedback as an additional layer of immersion or a possible option to resolve the contraction. Multiple prototypes were tested on multiple users as part of the user-centred design approach to ensure that the final results would provide people with the feeling of wing ownership. The result was that 100% of participants, six for the initial tests, agreed that hard-paper wings with feathers are the most suitable model.

The last experiment on the angelic avatar and flapping flight performed with 27 participants provided the following results. The arithmetic mean for of presence, avatar embodiment, and wing ownership were 5.5, 5.0, and 5.4 out of 7 in Likert scale respectively. In this study, we used the Likert scale to measure the extent of the participants' presence rather than interviews with yes/no questions or similar questionnaires. In response to the fourth research question, 85.2% indicated that they would pay up to 30 euro to play such a game in an amusement park or an arcade.

Conclusively, this study showed that future designs in the direction of flying must consider flapping flight as a preferable immersive model of flight. In addition to that, the expectation of the majority of people is towards an angelic form avatars which means the wings should be located on the scapulae.

In future research we will include (i) Integration of Flapping Flight and Gliding Flight and a Comparative Study, (ii) Adjustable Flapping Speed and its Effect on Immersion, (iii) integrating Haptic Feedback on Scapulae to Haptic VR Vests [12], (iv) Adjustable Flapping Speed and its Effect on Immersion, (v) Integration of Walking in a CAVE environment, and (vi) Correlation of Wing Perception and Cultural Background.

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