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Is there a way to provide mobility in a spatial direction within the virtual environment provided by Google Cardboard Virtual Reality System?

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ABSTRACT: *Google cardboard is a unique Virtual Reality System that's one of the first to provide the virtual experience via a smartphone using Gyroscope and Accelerometer built into the system. Even after being an effective system there's no way to emulate mobility in the virtual environment when it comes to activities such as running, walking and jumping. Walking in the virtual reality is achieved either by focusing on a target object or the environment is designed to move linearly automatically to give the sensation of mobility with neck movements to act as rudders-enabling users to experience the view at their own comfort in 360 degrees, yet unable to further advance the experience by letting them control their spatial body movement too. The study initiates with understanding how recognition takes place in a smartphone using the in-built accelerometer. It is derived that for measuring locomotion of body in any direction the device should be placed in that moving part of body but the smartphone in cardboard resides in the headgear. As the extremely low pricing of Cardboard is its redeeming quality; solutions like sensors and treadmill as input though effective are considered overpriced. A tangible mechanical system made of a cheap lightweight material that interacts through the screen sensitive strip built into the cardboard could be a possible solution. This solution is investigated through a study on how the body behaves while walking and the relative motion of its various body parts with respect to each other and how walking in virtual environment changes the gait of a person. The hindrance to natural movement in virtual environment is not only technical but also a consequence of human health, so finally a comparative study on simulator sickness brought on by different locomotion scenarios in virtual and real environment addresses this.*

Keywords*: Virtual Reality, Virtual Experience, Walking, Cardboard, Google Cardboard, Accelerometer, Smartphone.*

I. Introduction

Virtual reality or VR, also referred to as immersive media is a collection or a singular system that aims to stimulate physical presence in a virtual computer generated environment. The sensory modes of input to the person inside such an environment includes auditory, olfactory, visual or in some extreme cases gustation. With its widely accepted inception in the 1968 by Professor Ivan Sutherland and his student Bob Sproull with their Head mounted display Sword of Damocles which took up the whole room and was considerably huge for an HMD; the Virtual Reality gears have come a long way since then.

The Google Cardboard introduced in 2014 at the Google I/O developer's conference and created by David Coz and Damien Henry (Google engineers at the Google Cultural Institute Paris) in the same year, is one such revolutionary device which is immensely unique from the other devices in the same field. While other systems seek to make The Virtual Experience more immersive by incorporating as much of hardware and software as they can Google Cardboard has achieved a surprisingly efficient System at the percent of the cost and with the most simplistic of materials.

Google Cardboard is a cardboard cut-out which mostly exists as a do it yourself kit (DIY). It has 2 binocular sized holes where 2-34 mm diameter biconvex lenses are set at the suitable distance just as in a pair of glasses. The front side consisting of these lens spaces gets covered by a sheet of foldable cardboard from the front. Between the lens holes and the sheet there's just enough place for the smartphone to be inserted. The Cardboard lenses do the job of focusing the rays coming from the screen to the eye and projecting a virtual image which the user feels himself inside of. It is equipped with either a magnetic button or screen sensitive strip to interact with the virtual elements.

Such a simple concept of focusing the image from the phone screen onto the user and giving him the virtual experience by allowing him to move his head in different directions and subsequently seeing that particular part of the virtual field is what makes cardboard unique. They took an existing smartphone system and used it to make a virtual system a common man can afford.

But with the reduced cost come limitations. The user is able to change his viewing direction with his neck movements but is unable to control his movement with such control. Yes he can move because of some tweaks like focusing on a target object which triggers movement towards that object or in that particular direction. But an **Authentic walking experience** which will enable him to move with the movement of his legs is not seen as of yet in the various applications tested. This paper seeks to find the reason to the above mentioned problem based on the comprehensive study done by various research studies.

II. Studies Conducted

2.1 Activity Recognition using Cell Phone Accelerometers [1]

2.1.1Brief Description

The goal of WISDM (Wireless Sensor Data Mining)[1] project as described in the paper was to explore the research issues related to mining sensor data from mobile devices and to build useful applications using accelerometer as the sensor in study. Their study differs from previous study in the manner that they are using a single device to measure user activity rather than several placed across the body. They enlisted the help of twenty-nine volunteer subjects who carried the Android phone in their front
Pants leg pocket and were asked to walk, jog, ascend stairs, descend stairs, sit, and stand for specific periods of time. The data collection was controlled by a simple application created on android that registered the user's name and some other details and started and stopped the collecting of data. Sensor allocated was accelerometer.
The activities they carried out were observe and the data collected was in the form of spatial acceleration in 3 axes. Z-forwardly-vertical and x-horizontal. They made graphs of acceleration vs time and proceeded to observe where during mobility exercises like walking and running and jogging the periodic spikes occur. Y axis gave the most increased values as it was always being acted upon by the gravitational acceleration, then reduced was z and further very less was x. The data was collected in raw format and then converted to example samples. These samples were described in a table. Then they plotted other tables based on accuracy and confusion matrices which represented the confusion in the ability of the results to determine if the person was going upstairs or downstairs. This was verified using the walking statistics as walking is thrice as more while going up then going down. Many other such projects are mentioned and references for their research have been provided.

2.1.2 Observations

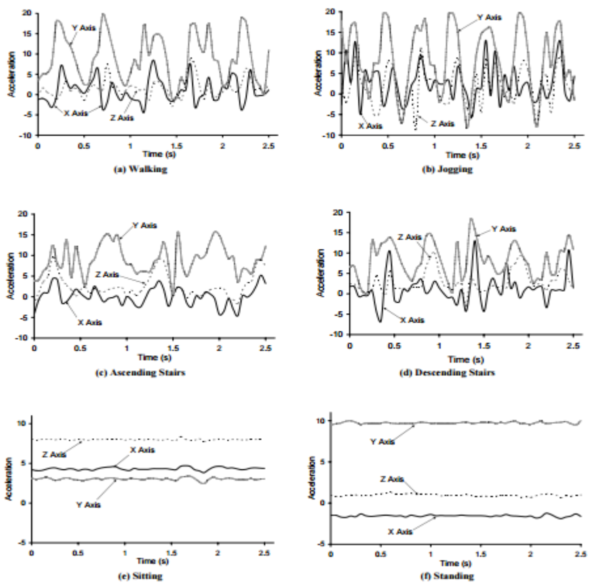

Figure 1: Acceleration Plots for the Six Activities (a-f) [1]

The plots depict how the accelerations in the different spatial directions vary with time. Y axis gave the most increased values as it was always being acted upon by the gravitational acceleration, then reduced was z and further very less was x.

2.1.1 Inferences

The inferences made from the research paper are as follows:-

1 The most important inference gained from the research paper was that the accelerometer detects the acceleration of the phone and not the part of body it is attached to. Now since cardboard keeps the phone in itself and its head mounted, the user's leg movement will not be detected at all.

III. Accelerometers are used to determine the orientation of device as they can sense the gravitational acceleration.

IV. They measure accelerations in 3 spatial directions, namely x, y and z.

V. On the basis of walk, jog, ascend stairs, descend stairs, sit, and stand one can prepare the factors/parameters that affect the accelerometers values.

VI. All 3 axis will have a spike during the mobility actions in the decreasing order of the amplitudes y>z>x if we consider y to be vertical z to be forward and x to be horizontal.

VII. Standing and sitting lead to the minimum of amplitude variations in the axis.

VIII. A need for confusion matrix exists to determine which operation is being performed. Like in the case of ascending or descending the stairs. Multiple data has to be analysed including walking. Walking is 3 times more while climbing then descending.

IX. The accuracy of determining the operation based on the accelerometer values is approximately 90%.

2.2 Effects of walking velocity on vertical head and body movements during locomotion [2]

2.2.1 Brief Description

It is usually concluded that the vestibular system plays a minimal role in maintaining posture and balance during walking [2]. In contrast, it has been suggested that the motion pattern of the upper part of the body is important for reducing energy consumption [2]. The study performed in this review is to establish a quantitative understanding of arm movement functions that can be obtained in terms of the relationship between arm movement and walking stability, this data will prove invaluable not only in the field of robotics research, but also in other fields such as sports physiology research, and medical research related to rehabilitation.

The main impact it will have on the overall study is to provide a way to determine which part of the upper human body best responds to the body movement so as to devise a mechanical model to implement the system of walking in virtual reality.

Aim of the study was to attempt to establish a relationship between:-

a. Stride Length
b. Stepping frequency
c. Vertical head translation
d. pitch rotation for head and torso
e. Head point

2.2.2 Experiment and Measurement

A study on 9 healthy subjects of similar height strapped with headband, heel markers and chest plate to keep track of translations was conducted. For each stride cycle the stride length, frequency, SLI (stride length index), pitch for torso and head, Head point Variations are recorded. These factors were mapped with walking speed.

The Measurement Apparatus in the study:-

1) Body movements were measured with a video-based motion analysis

   System (OPTOTRAK 3020, Northern Digital Inc., Canada)[2]

2) It was placed approximately 4 m from the subject.

3) Eight IR markers were placed on the headband

4) Four markers on the small plate attached to the chest.

The markers were 8 mm in diameter and 5 g in weight, and were connected to a strobe unit (94 g) that was worn on the subject's belt. The strobe unit was connected to a central control unit that fed the three-dimensional position data of each marker to a computer at a strobe rate of 150 Hz [2]. The markers and strobe unit did not interfere with natural movements of the head.

The different coordinate frames are visible in the figure 2. The vertical head translations along with the pitch rotation of head and body was measured in this experiment.

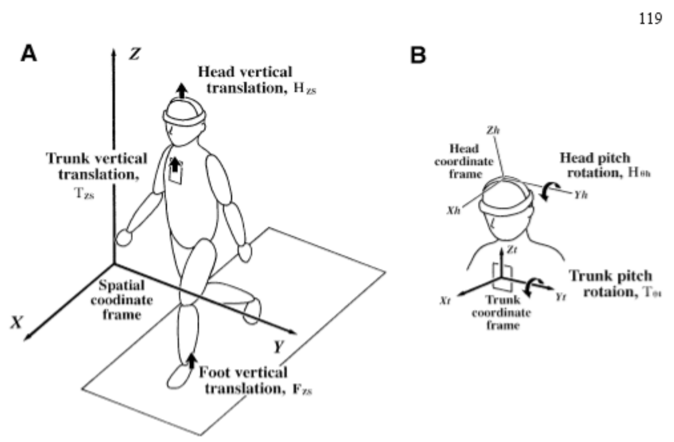

Figure 2: 1A, B Coordinate frames used in this study. A Vertical translation of the head (HZS), trunk (TZS) and foot (FZS) were measured in space-fixed coordinate frame [2] . B Pitch rotations of the trunk (T □ t) and head (H □ h)were estimated as rotations about bodyfixed Y-axes [2]

2.2.3 Observations

Each trial lasted 30 s and contained 15–30 complete stride cycles, depending on walking velocity. Stride length and step frequency are functions of walking velocity and were determined by the heel strike. Stride length and frequency are function of walking velocity given by V = F · S. The stride length index

Given by:

SLI= (log (S2/S1)/Log (V2/V1))*100

If the value is:

a. 50 %--> Half Stride Length contribution

b. 0 %---> Only Frequency contribution

c. 100% --> Only Stride Length contribution

All the data under uniform gait was considered for the 10 sec intervals

It was observed that the Stride Length during gait monotonically increased as a function of walking velocity for all the subjects. Same goes for mean stride length. And same for Stride Frequency for all regardless of height. The contribution of Stride length was determined by SLI. Between 1.0m/s-1.6m/s SLI-greater than 50% when SLI<50% frequency of steps changes. Finally, at 2m/s stride length saturates so Velocity varied only with frequency. At 1.2 m/s SLI was maximum.

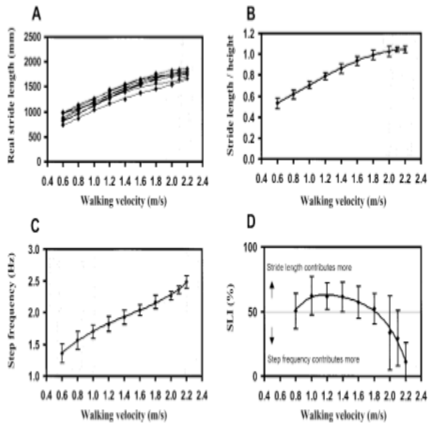

Figure 3: A Stride length of the nine subjects as a function of walking velocity. B Mean and SD of the relative stride length (calculated from the ratio of stride length to the subject's height) [2]. Stride length saturated above 2.0 m/s (shaded area). C Step frequency as a function of walking velocity. The rate of change of frequency was largest below 1.2 and above 1.8 m/s (shaded areas) [2]. D Stride length index (SLI), estimated using Eq. 1 in "Materials and methods." The curves in B, C, and D were fit by 4th-degree polynomials so that trends in the data could be observed. [2]

All the data under uniform gait was considered for the 10 sec intervals

It was observed that the Stride Length during gait monotonically increased as a function of walking velocity for all the subjects. Same goes for mean stride length. And same for Stride Frequency for all regardless of height. The contribution of Stride length was determined by SLI. Between 1.0m/s-1.6m/s SLI-greater than 50% when SLI<50% frequency of steps changes. Finally, at 2m/s stride length saturates so Velocity varied only with frequency. At 1.2 m/s SLI was maximum.

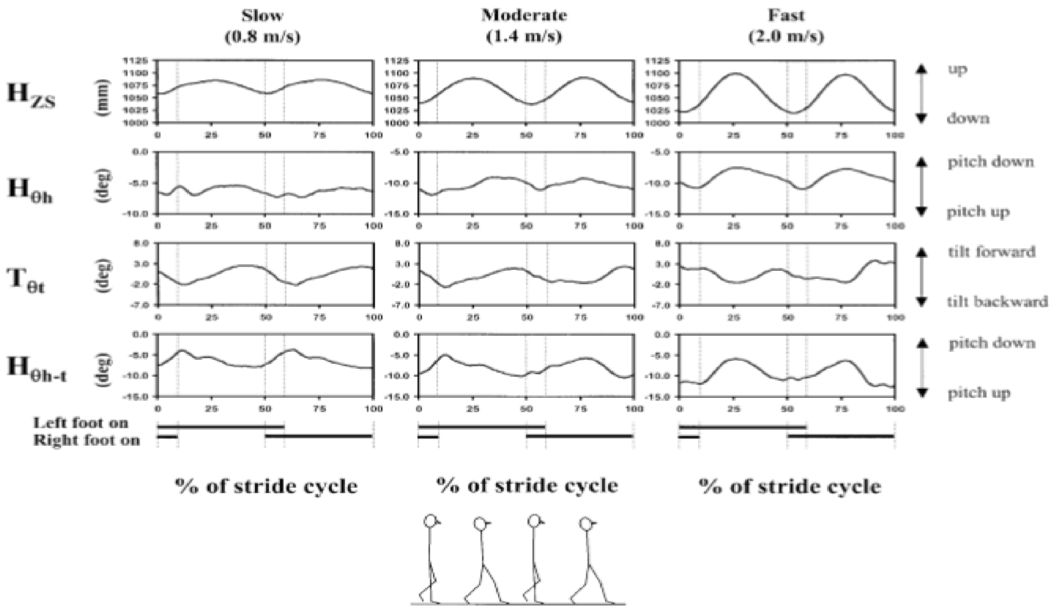

Figure 4: Typical averaged waveforms of HZS, Hθh, Tθt and Hθh-t for slow, moderate and fast walking from one subject (SM). The abscissa is the percentage of one stride cycle, which began with left heel strike and ended with next heel strike of the same foot. Each stride waveform is the average from 15–30 walking cycles, depending on the walking speed. The angular rotations of the head and trunk were zero (the reference position) when subjects were stationary looking at the visual target. Note that nose-down pitch rotations are positive [2]

The above figure shows how the vertical translation of head and torso along with their pitch rotations vary during walking. During stationary the angular rotations are taken as 0 of the body and the head and once the movement begins the rotation and translation is measured relative to it. One stride cycle starts from one heel strike to the next heel strike of the same foot.

During each stride cycle when the maximum force is given to the favoured foot to propel the person forward it is then that a considerable head translation towards the ground sets in. The person looks down to accommodate the head point view. Same goes for the head pitch as the head rotates about the axis when it propels itself forward. A similar variation is seen for the torso.

During the act of propulsion the torso tilts ahead to create the momentum of the movement and then it tilts back to conserve the inertia.

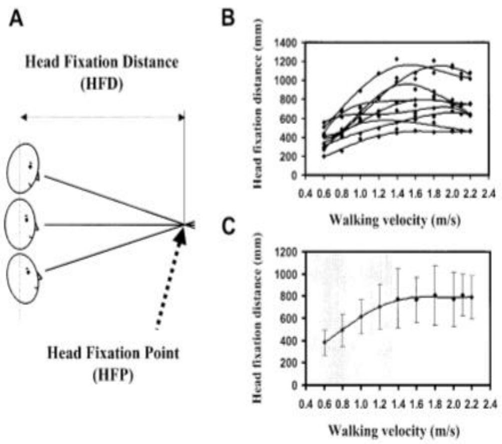

Figure 5: A The head fixation point (HFP) was defined as the point where the head roll axis intersects during compensatory pitch rotation and vertical translation of the head, and was estimated by triangulation. The head fixation distance (HFD) is the distance from the subject to HFP. B Distance from the head to the HFP as a function of walking velocity for each subject. C Mean distance to the HFP of all nine subjects. The distance to the HFP was relatively constant above 1.2 m/s (unshaded area) [2]

The point we look at while walking also drives the operation forward. If we look farther then according to the data the velocity increases in the same manner

As we see farther away from the target our speed keeps increasing until it reaches somewhat of a constant curve.

2.2.4 Inferences

The inferences made from the research paper are as follows:-

The most important inference gained got from the research paper was that there are multiple upper body parts which are affected in multiple ways through locomotion.

The factors getting affected or affecting the study's stability are:

a) Stride Length

b) Stepping frequency

c) Vertical head translation

d) pitch rotation for head and torso

e) Head point

Stride length and stepping frequency are related to the translation and rotation of head

Height does not vary the head point or the frequency very much.

The factors vary differently for different walking speeds which can provide me with a continuous function to provide mechanical responses for different speeds.

2.3 Real Walking Increases Simulator Sickness in Navigationally Complex Virtual Environments [3]

2.3.1 Brief Description

Movement in a virtual environment can generate various types of simulation sickness like disorientation, nausea etc. This paper serves as a comparative study to determine which out of real world, natural walking in virtual world and simulation walking cause the most amount of sickness.

Navigation is the key component to gauge the immersive nature of a virtual environment. The main component, walking is used in this study to drive the discussion forward. There have been carried out many experiments on the study of motion sickness prior to this one. Zanbaka and Suma [3] are two researchers who've conducted tests in this field but have done so in a small environment, restrictive in terms of time and space. So consequently their deductions or observations were severely limited and hence they couldn't reach a final conclusion or rather didn't see any such difference in the simulation sickness in the 3 conditions. A researcher by the name of Chance established that in some cases the natural walking in a simulated environment was less prone to sickness then the simulated one.

So due to lack of a proper measuring gauge or questionnaire the team led the study to warrant their question.

The method conducted consisted of a creation of a maze in their lab, a real tangible maze. It was followed by the designing of an almost similar maze in a virtual reality software. The test subjects chosen where allowed a period of five minutes to travel in either of the 3 conditions in randomized error. Where the three conditions were:-

VNW: Natural walking in virtual environment
VSW: Simulated walking in virtual environment
RW: Real walking in real environment

They were also given a one minute test time to get used to the simulation software. The Kennedy-Lane Simulator Sickness Questionnaire (SSQ) [3] was given before and after the testing and the overall sickness score along with that in each condition was recorded for each type of discomfort i.e. nausea disorientation and oculomotor discomfort.

2.3.2 Observations

The result on the 90 test subjects where 30 were in each condition showed drastic deviation in some cases and none in others. The results were influenced on the basis of the travel technique; the total and the individual simulator sickness changed. None of the deviations were much significant except for disorientation during VNW.

So Natural walking in virtual environment produces the most sickness while that in real and simulated remains the same and in some cases even lessens. So this proves that simulated walking is a better way to navigate highly complex mazes and probably because the physical effort required is less.

		Before	After
Overall	RW	18.95	12.72
	VNW	18.20	29.17
	VSW	15.46	14.46
Disorentation	RW	12.99	11.60
	VNW	14.85	37.11
	VSW	13.92	14.84
Nausea	RW	13.99	10.81
	VNW	10.81	19.72
	VSW	8.59	9.22
Occulomotor	RW	18.95	10.86
	VNW	19.96	23.25
	VSW	16.42	13.90

Table 1: Mean Simulator Sickness result [3]

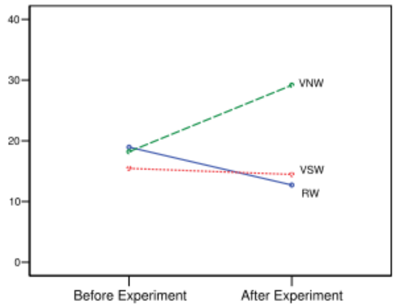

Figure 6: Overall Simulator Sickness Score [3]

2.4 The influence of virtual reality systems on walking behaviour: A toolset to support application design

2.4.1 Brief Description

The paper deals with the effect of a number of factors within VR systems on walking and movement perception [4]. Even normal walking is hindered due to any injury to the legs or any form of disease that can reduce or change walking patterns. The walking in a virtual environment is dependent on walking interface, visual gain, and audio tempo [4]. The relationship between walk length and stride length and the tempo or frequency is altered by the walking interface and visual gain [4]. Our own perception of how we are moving is altered by what we see from the corner of the eyes or how far wide we can see, the brightness, the size of what we see etc.

This study will help understand the various factors to be keep in mind while designing the solution to the Problem a mechanical solution was the way to solve the problem as of yet, envisioning ideal conditions and assuming that **the walking in real and virtual environment won't vary at all. But it does.**

The study begins with the description of the various factors that can cause the variation in walking in virtual reality including perception, interface and tempo, stride length etc.
Virtual rehabilitation helps keep the injured person engaged and takes his mind of the pain. So research into this matter to provide efficient and friendly systems/applications is necessary. Cadence is the frequency of heel taps on the ground between the stride of the two legs while stride length is the length from the left footfall to the right during one step. It has been seen that the walk ratio which is the relationship between the walk stride and cadence remains same for a range of speeds, so for a consistent experience walk ratio and speed should remain similar.

Real world movement is controlled by vestibular and stimuli and visual perception but since these might change in the virtual reality it's difficult to emulate actual walking. But there are systems that can change the variables like the interface, the environment to provide every kind of virtual terrain to alter the perception of the user and suit real conditions.

The input devices to measure user movement can be of 3 general types:-
1) Mechanical: Restricts user movement a lot so not a valid way to study walking behaviour.
2) Sensor based: Freedom is unlimited but the position of sensors also matter, some movements may require the use of changing body patter to match sensor pattern. Also fear of falling off can also affect change in walking pattern in virtual environment.
3) Using Treadmill: The most convenient way to measure the movement since it provides a linear direction to measure, it can be changed to match user autonomy over movement. Also require less space and give the feel of walking over ground. This system has been employed in the study.

Output devices:-
For giving feedback to the users the main channels are the visual and auditory. So, big flat screens or head mounted displays and speakers or headphones are used. Factors such as display size, field of view, display resolution, refresh rate and color fidelity all vary between different output devices [4]. Since the input device is a treadmill hence it's necessary that the user knows his bounds, a head mounted display though provides an extreme immersion it also provides perception distortion and the inability of the user to judge real world obstacles. Hence Screens put around the user are much more efficient on this manner. Due to Lack of studies it's

not clear how the difference between the two will affect user pattern. By thorough testing the decisive field view that provides natural perception would be in the range of 80’ and 200’.
The display taken into consideration is stereoscopic since studies show that it increases depth perception and the visual perception varies greatly.
Virtual Environment:-
The video content provided by the environment is usually filled with abstract or literal cues. Like dots moving behind will give the illusion of walking hence the user will move forward consequently but other studies have used actual literal environments like a street or a rollercoaster to invite user to move. Peripheral video matters as it affects user perception of a situation. Also the contrast of the abstract cues like dots changes the user speed like brighter dots appear to move faster.
Audio input like music or external noise can also affect gait as the user can be disturbed while walking or increase his tempo based on the beats of the music. Again enough study has not been conducted regarding this problem.
Calibration and scaling also form an important factor for user walking pattern as the size of the entities in the virtual environment should be as real as possible to sate the mind of any confusion and hence disrupting a certain Candace. The user also expects things to scale as he/she approaches or moves back. Not in the least the speed at which the virtual environment displays the environment going by can also lead to increase or decrease of speeds.

2.4.2 Observations and Inferences

Table 2: A TOOLSET TO DETERMINE THE EFFECT OF VARIOUS VR FACTORS ON WALK SPEED, WALK RATIO; VISUAL FLOW PWERCEPTION, IMMERSION AND SPACE/TRACKING REQUIREMENTS [4]

VR factor		**Effect on walk speed**	**Effect on normal walk ratio**	**Effect on self-motion perception**	**Effect on immersion**	**Space / tracking required**
Walking interface	**Free walking (with HMD)**	May lead to ‘cautious walking’ (+)	No data	HMD required - see separate heading	HMD required - see separate heading	Large spaces. Tracking can be complex.
	Self-paced treadmill	Baseline walk speed reduced by around 25%	Normal walk ratio maintained	Self-speed estimation increased by around 10%	Natural walking may increase immersion (+)	Can be used in restricted spaces
	Motorised treadmill	Walk speed pre-set by operator	Walk ratio decreased by around 10%		Fixed speed may reduce immersion (+)	
Visual content	**Peripheral visual cues**	Lack of cues may affect visual flow – see **visual gain**	No direct effect	Increased accuracy of self-motion perception	No direct effect	N/A
	Correct scaling of geometry	No data			Increases immersion	
	High visual contrast	No direct effect		High contrast gives impression of faster visual flow	No direct effect	
	Visual gain	Visual gain 0.5:1.0 increases walk speed by around 10% (*)	Lower visual gain increases stride length	Visual gain between 1.5:1.0 and 2.4:1.0 appears ‘normal’	Lower visual gain may decrease immersion (+)	N/A
Visual delivery	**Head mounted display (HMD)**	No direct effect. Cautious walking more likely (+)	No direct effect	Reduced accuracy of depth and motion perception	Higher immersion than flat screen	Head tracking necessary
	Large-screen display	No direct effect. Needs to be used with stepping in place or treadmill	No direct effect	Less perceptual distortion than HMD. Wider FOV possible	Less immersive than HMD	No head tracking required.
	Stereoscopic projection	No direct effect	No direct effect	Increased accuracy of self-motion perception	Increased immersion	N/A
	Monoscopic projection	May reduce the effect of visual flow modulation	No direct effect	Decreased accuracy of self-motion perception	Decreased immersion	
	Field of View (FOV)	FOV < 80º reduces peripheral flow and thus may reduce visual flow modulation effect	No direct effect	Increased accuracy of self-motion perception with FOV > 80º	Increased immersion with wider FOV	N/A
Audio content	**Tempo**	Increased walk speed by 15% with tempo 25% above baseline cadence	Normal walk ratio maintained	No data	No data	N/A

III. Discussion

Table 3: Comparison of Different Methods

	Ease of Implementation	Cost of implementation	Effect of External Factors	Tangibility	Error finding	Workload
Software Solution	Hard	No cost	No effect	Non Tangible	Hard because exists in complex code.	The real workloads are infinite as the user can do any action.
Mechanical Model	Easy	Negligible cost	Humidity affects	Tangible	Errors are all mechanical so easy to fix.	Real workload is restricted to normal user movement.

The table depicts the comparison between different Solutions that can be employed implemented to solve the problem of walking in virtual reality.

Though the Software solution will be more flexible and efficient by a large degree; it'll also be harder to implement. Too many workloads to process and the error handling becomes difficult,

The mechanical model will be cheap, Tangible and mostly error free. But it'll restrict user workload and can be affected by external factors like humidity and precipitation etc.

IV. Conclusion

It is possible to implement a system which will enable us to carry out mobile activities like walking, running jumping etc. The system can be implemented
By either software or hardware method. The software method though more flexible in terms of the movement scenarios it's able to provide is hard to implement because of the limited amount of Application programming interfaces(API's) present. Also it's difficult to work with the smartphone accelerometer as it can detect even the most smallest of acceleration vectors hence ruining the movement. The accelerometer also detects the movement of the body part which it's attached to so leg movement will be hard to detect.
The mechanical model is easier to implement. It can consist of a tangible connecting device made of a flexible material that will connect the legs, hands or some other organ of the body which responds to the walking stimuli like head as discussed in [2]. It would be less prone to errors as it's a physical device. But it'll be hard to determine the performance metrics during the research as its dependent on many factors such as pitch, stride length and stride frequency etc.

The idea of walking in virtual reality using your legs can provide quite an immersive experience but this can also lead to increase in the amount of simulator sickness that arises from the increased mode of input by the user through his legs. He/ She will feel disoriented and nauseous by the amount of control they have in the virtual environment.

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