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MOTION SICKNESS PREDICTION DEVICE FOR AUTOMATED VEHICLES

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Abstract - Motion sickness is a persistent problem in many forms of transport. It affects most of the population, is debilitating for the sufferer and can disrupt the journey for the rest. Automated Vehicles (AV's) offer greater flexibility in cabin design particularly in the future where no physical controls are required. This poses additional risks to passenger wellbeing with increased levels of motion sickness when passengers and historical drivers are multi-tasking. This study demonstrates a device that can predict real time occupant motion sickness based on motion, head tilt and ambient conditions. Recovery is also considered for multiple journeys. The device can be easily modified to reflect an individual's susceptibility or use group settings for the general population.

Index Terms - Automated Vehicle, Motion sickness, Wellbeing, Prediction.

I. INTRODUCTION

Automated Vehicles (AV's) are today becoming a reality. Several pilot studies are underway with most Original Equipment Manufacturers (OEM's) declaring their intention to be part of an autonomous future. Numerous concepts have been revealed at motor and consumer electronic shows with the Renault "Symbioz", Smart "Vision EQ", Honda "Urban EV Concept", Audi "Aicon" and Panasonic "Cabin Concept" being amongst the most recent examples.

Many of the cabins include flexible lighting, aroma, air quality, massage seating and other comfort and well-being features. Wellbeing is a total care package that aims to improve both physical and mental health of the occupants. Initially this was exclusive to luxury vehicles, it is now evident on more modest vehicles with pollen and pollution screening being widely used.

It could be argued that the prime objective of an AV cabin is to reduce 'non-value add' and increase 'value-add' time for all occupants by enabling additional productivity, enjoyment and well-being features. A recent study into different commuter options has recently been investigated [1]. It wasconcluded that if the commute can add value regardless of mode then the satisfaction of that commute is significantly increased. D. MacKenzie, Z. Wadud, and P. Leiby suggest that the 'time-cost' saving for journeys for AV's could be as high as 50% and 80% in some extreme cases when non-value add is reduced [2]. It is therefore paramount to maximise the time available in an AV to be engaged in productive activities to fully realise the time-cost benefits. Therefore, the ability to engage in Non-Driving Related Tasks (NDRT) is an essential part of making the journey 'value add'. To maximise productivity, many of the proposed concepts depict fully flexible seating within an office-like environment. Enabling technologies such as large touch screens for digital input with centre tables are widely used in AV concepts, Fig.. The driving task will be fully automated to manage the motion and flow with other road users thus leaving all occupants to be free to engage in NDRT's.

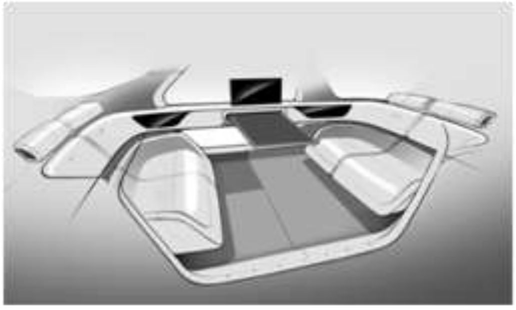

Fig.1 Common theme for Autonomous cabins (Courtesy of JaguarLandrover)

This poses many challenges, connectivity on the move, integration of your data, being able to function with dexterous tasks whilst subjected to motion are but a few [3]. Diels & Bos (2016)comprehensively describe the challenges that driverless vehicles pose regarding motion sickness [4]. Diels (2014) also discusses design implications of AV's and concludes that the design should maximise the ability for occupants to anticipate the future motion path of the vehicle and minimise the likelihood of conflicting motion cues [5]. Wada (2016) also discusses the potential changes to AV design and usage in the context of motion sickness.

Motion sickness occurs if the motions as sensed via our sensing systems is different from what we expect them to be. A classic example being reading a book in car. The stationary visual scene and associated expectation that the body is not moving, is incongruent with the accelerations sensed by the occupant within the vehicle. This can lead to motion sickness as described by the sensory rearrangement theory by Reason & Brand (1975)[7]. There are other theories, an alternative is that of postural instability. Riccio & Stoffregen proposed that again incongruent sensory information in the maintenance of balance leads to motion sickness when there is incongruency between the observed and sensed, [8].

In both the error is between the perception and reality of low frequency large amplitude motion to the visual signals. The literature to date has been limited to a small number of on-road tests with conventional road vehicles. Griffin & Newman [8], Turner & Griffin [9] and Wada, Konno, Fujisawa, Doi [10] are notable studies. Griffin found the exterior forward view from within the cabin to be influential in reducing motion sickness. It is known that human drivers in conventional vehicles are less prone to motion sickness being part of the control loop for the vehicle motion. Rolnick & Lubow suggest that having an anticipation of motion leads to a good match between the expected and observed motion, [11].

This is clearly demonstrated when drivers tilt their head into a bend, passengers are passive and exhibit a general trend for centripetal motion leaning with the motion in the opposite direction, [12]. It has also been shown recently that peripheral vision is key to the propensity of recorded motion sickness, this has significant implications for the design and positioning of in-vehicle displays [13]. The plethora of NDRT’s and multi-tasking opportunities that feature in many of the concepts for AV’s could limit the anticipatory antidote for motion sickness, particularly if the occupants are engaged deeply with a task and perhaps miss the cues on offer.

Reason and Brand suggest that motion sickness is known to affect some two thirds of the population at some point in their lives [6].

It has been estimated that the increase in occurrence for motion sickness within a conventional cabin driven autonomously leads to a 6-12% increase in frequency and severity due to the possibility of NDRT’s, [15]. This is however only antonym and merely an extrapolation based on rather little data. The percentage increase indicated is hypothetically based on task. In contrast Kuiper found exact symptomatic motion sickness data for a specific feature of future vehicles for a prescribed stimulus. Kuiper for example has shown that for auxiliary screen height alone there could be around a 40% increase in sickness symptoms[14].

Historically, motion sickness has been evaluated by self-report by the sufferers using one of the many motion sickness scales available. FMS (Fast Motion Sickness scale) [16]and MISC (MIsery Sickness Scale)[17] are notable and widely used self-report subjective measurement techniques. Quantitative measurements are focused on capturing data from the Autonomic Nervous Systems (ANS) response to motion sickness, a change in physical state due to the build of motion sickness. Current literature coupled with the ease of measuring heart rate variability (HRV) leads to many recent studies focusing on HRV standardised metrics [18].

However, cardiovascular changes due to motion sickness offer limited insights into levels or indeed incidence [19].

The purpose of this study was to develop a motion sickness meter that could predict the subjective feelings of sickness based on the provocative low frequency motion of the vehicle using Motion Sickness Dose Values (MSDV) [20], the task (ocular-vestibular tilt) and ambient environmental conditions. It is widely known that reading causes motion sickness in vehicles whereas gaze forward generally does not [21].

We hypothesise that a real time device should be able to track the rise and fall of motion sickness congruent with motion and other environmental factors during a drive when conducting Non-Driving Related Tasks (NDRT’s) on an individual or group basis.

II. REQUIREMENTS OF THE MEASUREMENT DEVICE

The minimum requirements for the device are listed in Table 1.

Table 1 Device Requirements:

1) Objective score for motion dose.
2) Subjective score for sickness.
3) Ambient temperature sensitive.
4) Store values for future interrogation.
5) Portable, pocket size.
6) Log occupant head position.
7) Variable for sensitivity tuning, personable.
8) Programmed healing and recovery.
9) Real time display and calculation.

III. WELLBEING SUBJECTIVE SCORE (WSS)

All measured journeys for the data collection were scored subjectively against a standardised scoring system 0-10 with emesis at 0, no symptoms=10, onset of nausea=4.

The symptomatic attributes are identical to the respected MISC scoring system with the exception of the numerical score reversed [17]. Reversing the numerical scoring aligns with typical OEM vehicle development where increasing scores are congruent with positive attribute scoring.

IV. METHOD

The study was conducted under local code of conduct and risk assessments and finally Coventry University Ethics P65717. A prototype device utilising an Arduino processor, OLED display coupled to an Inertial Measurement Unit (IMU) was developed to capture the acceleration of the vehicle. The subjective score for sickness in this paper was based on a single user trial of over 100 samples from a wider study of over 1500 measurements. The appropriate acceleration and ambient conditions are used from the larger studyare used to determine the algorithm and functional gains such that the resulting Well-being Subjective Score (WSS) closely matches the subjective response for those conditions. The algorithm and device were developed over 53 iterations for both physical and software builds.

A functional schematic of the motion sickness measurement device is shown in (Left), the final device is shown (Right).

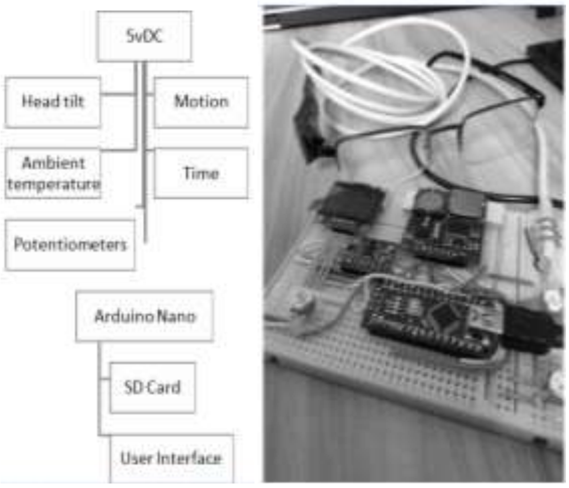

Fig 2. Device schematic (Left), Head tilt measurement version (Right)

This device consists of the following components
A. Tilt-switch + Glasses
B. DS1307 Real time clock
C. MPU6050 6DOF+temperature module
D. SD CARD module
E. U8X8_SSD1306_128X32_UNIVISION_HW_I2C u8x8 OLED Display
F. IC/I2C/TWI 2004 20X4 Character LCD Module Display
G. Arduino Nano 32kB processor ATMEGA328, CH340 USB
H. Breadboard
I. Assorted jump wires
J. 3x Trim-pot 10K

The computer program in a schematic is shown in Fig.. Syntax for Arduino code is fundamentally C/C++. The libraries that are needed to run the modules are also coded in C++. Once the code is written, it is compiled within proprietary workbench software and then uploaded to the Arduino board. The Arduino board only has 32kB of ram with some partitioned off for essential boot loaders. This leaves around 28kB for useful programming. This small size is limiting for higher functional use. However, it does mandate a level of clinical efficiency in the code. Use and re-use of variables and computing information at integer bit level rather than conversion to an SI unit is necessary to keep the code below the memory capacity of the device.

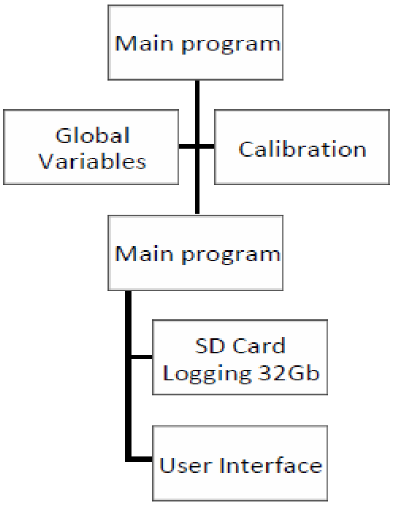

Fig.3 Device software schematic

Libraries included: OLED, I^2C bus, IMU, CLOCK and SD card logger. The OLED library was limited to text only. The program generates an effective cumulative damage for motion using the accelerations recorded by the IMU in accordance to Motion Sickness Dose Value (MSDV) [20], [22]. The IMU data is summed to provide a single vector from the three translation acceleration values. Gains are added for head up and down conditions so that the increase in sickness is reflected for the head down state. The device calculates in real time with live output displayed on the OLED screen. The frequency banding is achieved by an equivalent band pass filter using an Exponential Moving Average filter (EMA),[23], (1). $S_t = \alpha Y_t + (1-\alpha)S_{t-1}$(1)
Where S_t is the output of the EMA at time t, Y_t is the potentiometer measurement at time t, and α is a coefficient in the range <0,1>. Low values of α lead to a slow response to rapid input changes.Conversely highα will be more responsive and averaged over fewer samples.Simply,α isakin to a cut-off frequency in a low-pass filter.The EMA parameters were iterated during a tuning phase so that a known and reliably provocative route resulted in congruent output with respect to looking forward / down modalities. The EMA process conditions the acceleration data similar to Tschebyshev 2nd order 0.00005-0.16Hz Band pass Fig. (Top) which is similar to ISO2631 W_f weightings [22]. Improved correlation was achieved to the subjective score (WSS) by lowering the low frequency cut off to include more low frequency motion, this is congruent with the findings made by Donohew and Griffin for lateral vehicle motion[24]. The equivalent filter developed within the device is illustrated Fig. (Bottom). A t-test indicates that there is not a significant difference between the meter EMA and

the Tschebyscheff equivalent filter ($t=0.51, p>0.05$, Pearson=0.97, $p<0.001$).

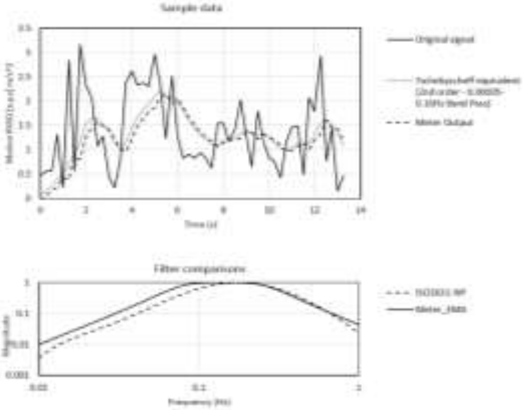

Fig.4 Filtering of raw acceleration data using an Exponential Moving Average Filter EMA Input: Output (Top), Effective frequency Filter (Bottom)

The device is also temperature sensitive, it was found that for very cold and hot conditions the feelings of wellbeing were less than those for a more thermal neutral environment with similar motion levels. The device therefore limits or builds dose based on the ambient temperature. A functional temperature map used is illustrated in Fig.. The temperature map was developed using data captured during hot and cold ambient temperatures (11-32 DegC).

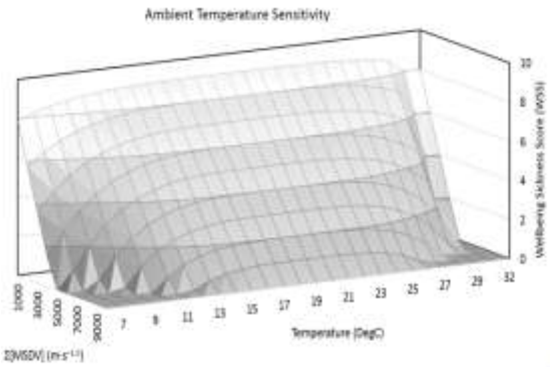

Fig.5 Dependency of Well Being Subjective Score from ambient temperature and Motion Sickness Dose ValuesAmbient Temperature function

The predictive sickness score is developed using a time-based function(2).

$$f(WSS) = [\sum_{t=0}^{t} f(M)f(Hg)f(T)]f(R)(2)$$

Where, f(WSS)=Subjective score for sickness, f(M)=Band passed Root Sum of the Squares for X,Y,Z accelerations [$m.s^{-1.5}$] as per Fig.4,f(T)=ambient temperature function. f(Hg)=Head gaze function to describe looking forward or looking down. f(R)=recovery function. Each function uses gains that can be modified to match the occupant's unique personal sensitivity.

A. Route and vehicles

Multiple routes were measured during the data collection phase. All journeys were more than 30 minutes duration on 'A/B' roads and motorway sections. The study contained 101 trips, 53 Looking forward and 48 looking down. All samples were taken from a window seat in either large passenger coaches or 14 seat minibuses as a passenger. This study uses data from multiple seating positions along the length of the vehicles with 52 samples taken from the centre to the rear and 49 from the centre to the front. Ambient temperature was controlled by the vehicles air conditioning system and for this study had a (Mean=22.8DegC, SD=3.4). The data used in this study was in excess of 2500 measured miles.

B. Confirmation Stimuli and environmental conditions

The confirmation journey used a single measure of looking up, down and was approximately 50 Miles and 60 minutes travel using a 2016 MY Mercedes minibus using the same driver. The temperature for the confirmation test was controlled by the air conditioning of the vehicle having a Mean of 21.41, SD=0.63Deg C.

The outside weather was partly cloudy, 8:30am sun elevation levels in May (UK), external temperatures were 17 DegC rising to 18 DegC for the duration of the test. The levels of accelerations are illustrated in Fig.1 processed to DIN45667 [25], (Gravity compensated and re-sampled to 2.5Hz). Descriptive statistics are shown in Table 3.

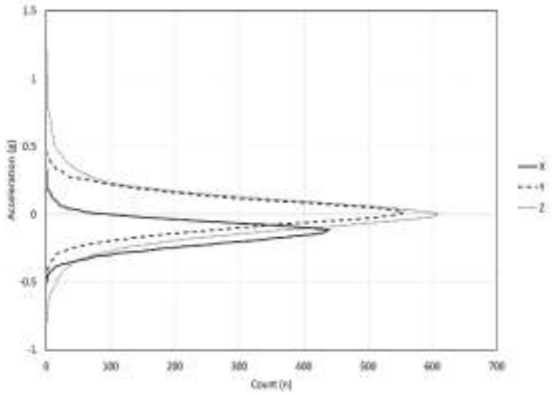

Fig.1Probability density functions of measured accelerations in X, Y and Z directions according to DIN 45667, Mercedes mini bus motion

Table 2 Confirmation stimuli descriptive statistics

	X(g)	Y(g)	Z(g)
Mean	-0.01	0.02	-1.00
SD	0.05	0.07	0.07
Max	0.20	0.46	0.26
Min	-0.29	-0.30	-0.40

V. RESULTS

C. Data collection results

The looking up and down data for the study are illustrated in Fig..

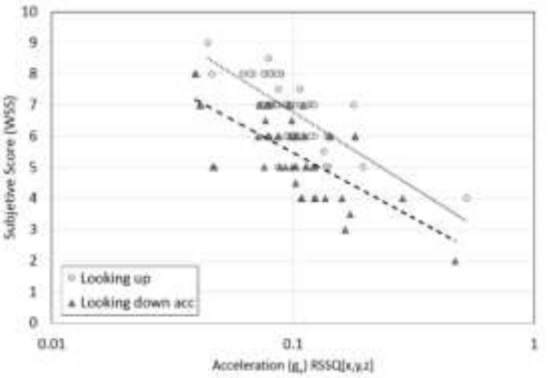

Fig.6 Comparison of looking up-down subjective scores [WSS] with respect to filtered RSSQ acceleration (g), [g_a=Tschebyscheff 2nd order 0.0005-0.16Hz Band Pass]

Using a quadratic regression model on each data set yields a significant fit between the acceleration (g_a) and the resulting subjective score (WSS), (r^2=0.61, $p<0.001$, r^2=0.63, $p<0.001$) for looking up and down respectively. Comparing the subjective scores for the two conditions there is a significant difference between looking up and down (t=5.77, $p<0.001$, Mean=5.48, SD=1.29, Mean=6.83, SD=1.03) for looking up and down respectively, Fig.. Additionally, there is no significant difference between the acceleration data for the two conditions (t=-0.45, $p>0.05$, Mean=0.11, SD=0.065, Mean=0.11, SD=0.069) for looking up and down respectively.

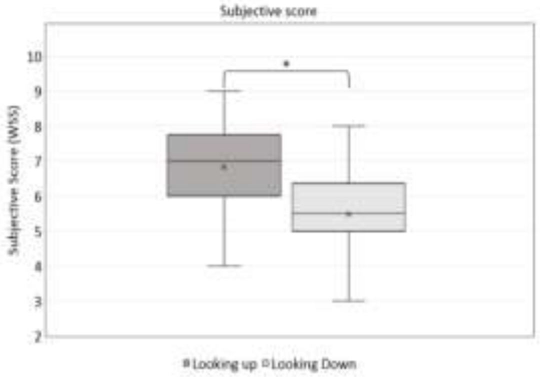

Fig.8 Differences of Wellbeing Subjective Score for looking up – down

D. Meter prediction

The meter outputs both motion dose and a subjective score that is dependent on head tilt, i.e. looking up or down coupled to local ambient temperature. The output from the device is illustrated in Fig.. A t-test indicated that there is a significance between both the MSDV output and WSS for looking up and down modalities, Table 3.

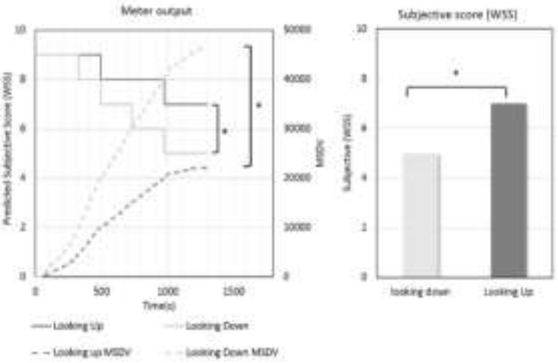

Fig.9 Motion sickness device output (Left), Subjective score (Right)

Table 3Device output

	N	Mean	SD	T-Value	P
$MSDV_{up}$	5191	12305	7718	116.6	<0.001
$MSDV_{down}$	5191	25092	15609		
WSS_{up}	5191	8.13	0.78	105.7	<0.001
WSS_{down}	5191	6.94	1.52		

The nonlinearity of the device is highlighted with a gearing down from the MSDV differences to the WSS differences for the same condition.The two data points used in the correlation analysis are illustrated within a wider wellbeing study in Fig.. The wider study is part of a large research package into motion sickness within AV's for future publication.

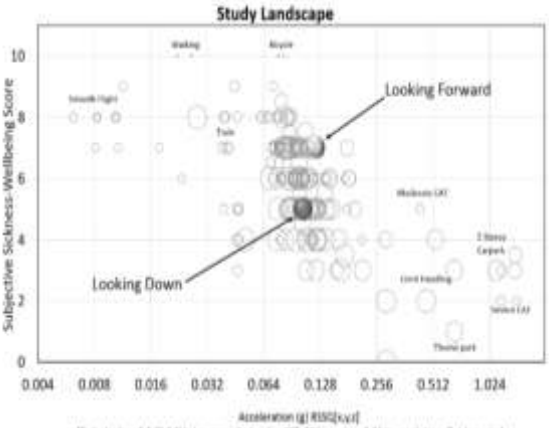

Fig.10 Well-being study landscape, correlation data samples highlighted

E. Recovery-healing example

An example of recovery is illustrated in Fig.. The decay and restart of dose build can be seen during a journey with a 10-minute stationary period. Short stops do not reduce the levels, reductions build the longer the stop. It can also be seen that the looking down condition takes longer to recover due to a deeper level of assumed motion sickness.

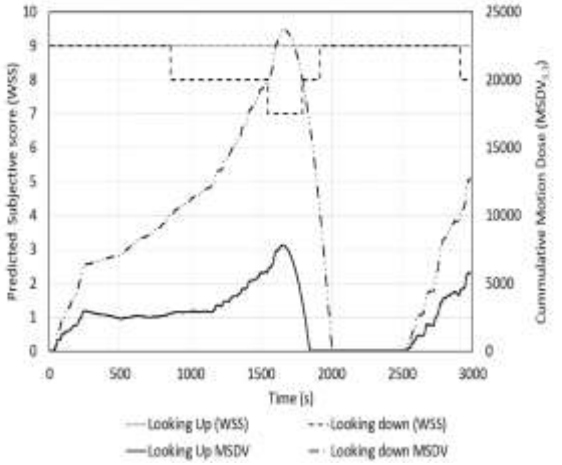

Fig.11 Example of the recovery feature within the motion, Subjective score (WSS), MSDV=Cumulative motion dose (g) for RSS [x,y,z]

DISCUSSION

It was noted during the testing phase that on the coaches and particularly the minibus anticipatory cues were readily available to predict some forms of upcoming motion. The axle whine provided useful information as to the gross forward velocity of the vehicle and foresight to longitudinal shuffle events. The engine and exhaust tone coupled to forward acceleration provided additional cues and was easy to anticipate the shuffle from future gear changes. Multiple repeats of the same journey with a downward gaze did provide a rudimental memory of map future vehicle motion. This anticipatory map was only disrupted by unpredictable traffic conditions. It is known that anticipation of future motion can improve motion sickness [17],[26]. Similarly it has also been found that sickness could be reduced by an average of 50% by providing information about earth fixed horizon in flight environments [27]. The output of the device is tuneable to match sensitivity for any occupant. In this instance it was tuned to match the susceptibly of the researcher being around 55%ile using MSSQ Short[28]. The overall evaluated dose presented a 51% difference to motion coupled to gaze resulting in a conditioned 17% difference in subjective scoring. Kuiper found around 43% difference in illness scores for a looking up and down task based study [14].

The algorithms employed within the device use simple RSSQ with no weightings for directions. This will be refined further using information from future research studies regarding directional weighting. Albeit, there is reasonable agreement of this study with the weightings proposed by Donohew and Griffin in addition to the methodology described within ISO2631/BS6841, [24], [22], [20].

The device has proven reliable in its development ‘breadboard’ form. Future versions will be optimised units using smaller protected form factors. Larger screens have been since integrated so that they are easier to read whilst under motion.

LIMITATIONS

All of the data presented in this paper uses parameters tuned to the subjective response of the researcher. The data set includes data obtained during a wider N>1500 case study encompassing most land and air-based transport. Unpublished multiple user trials have also been undertaken and show similar levels of agreement between the predicted and reported levels of sickness.

CONCLUSION

It is demonstrated here that an effective wellbeing-motion sickness monitoring device can be used to predict a subjective rating congruent to standard motion sickness scores. The device can be tuned to any participant’s susceptibility either by modification to onboard potentiometers or recompiling using locked variables. If there is no motion detected after a prescribed time, then the unit reflects simple recovery. Future developments may include habituation functions with personalised parameters for multiple occupant monitoring within the same vehicle including remote eye and head tracking.

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