Latency in Visionic Systems: Test Methods and Requirements

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ABSTRACT

A visionics device creates a pictorial representation of the external scene for the pilot. The ultimate objective of these systems may be to electronically generate a form of Visual Meteorological Conditions (VMC) to eliminate weather or time-of-day as an operational constraint and provide enhancement over actual visual conditions where "eye-limiting" resolution may be a limiting factor. Empirical evidence has shown that the total system delays or latencies including the imaging sensors and display systems, can critically degrade their utility, usability, and acceptability. Definitions and measurement techniques are offered herein as common test and evaluation methods for latency testing in visionics device applications.

Based upon available data, very different latency requirements are indicated based upon the piloting task, the role in which the visionics device is used in this task, and the characteristics of the visionics cockpit display device including its resolution, field-of-regard, and field-of-view. The least stringent latency requirements will involve Head-Up Display (HUD) applications, where the visionics imagery provides situational information as a supplement to symbology guidance and command information. Conversely, the visionics system latency requirement for a large field-of-view Head-Worn Display application, providing a Virtual-VMC capability from which the pilot will derive visual guidance, will be the most stringent, having a value as low as 20 msec.

1.0 INTRODUCTION

A visionics device provides a pictorial representation of the external scene (i.e., the external environment in which the aircraft is flying), generated by electronics means such as electro-optical sensors, radars and/or a database (synthetic vision). Night vision systems and image intensifiers – two examples of visionic devices - have opened the operational capabilities of military organizations such that they can now "own the night." Synthetic vision and other emerging visionic systems technologies, such as forward looking infrared, and millimeter wave radar, are offering the potential of freeing the pilot from the limitations imposed by restricted outside visual references. Military and commercial operators can now also "own the weather."[1]

The ultimate objective of these systems may be to create a "Virtual-Visual Meteorological Conditions" (Virtual-VMC) capability. This environment is called "virtual", as it is electronically generated, but it is more accurately described as an augmented reality to eliminate weather or time-of-day as an operational constraint and provide enhancement over actual visual conditions where "eye-limiting" resolution may be a limiting factor. For commercial operations, the potential of Virtual-VMC offers safety and capacity superior to present-day, clear-day operations whereby it could eliminate the dichotomy of Instrument and Visual Flight Rules, enable arrival and departure procedures to be weather-independent, and maintain airport / airspace capacity and safety at all times and all weather conditions.

1.1 Visionics Latency

The imaging sensor technology behind these visionics devices is the first-and-foremost determinant in creating a Virtual-VMC capability. However, a critical determinant which could ultimately decide the utility, usability, and acceptability of these visionic systems may be the delay or latency between the time that emitted or reflected energy from the object is sensed in the outside world, until that object is represented on a cockpit display to the pilot. Similarly, delay or latency is involved in the generation of a Synthetic Vision / database image as well.

The first-order effect of latency in a visionics device is that the visionics "world" appears to swim about or oscillate. Performance in terms of the user's interaction with the visionics-created world degrades. As latency increases further, image stability can be lost. This paper will review methods to measure visionics device latency and attempt to quantify its effects.

2.0 BACKGROUND

In many works, latency definitions or measurement techniques have not been well-understood. Actual measurements have often not been made. Without common tools to measure and assess latency, requirements to develop visionics will not exist and latency problems will forever remain. Time delay sources and accepted measures are briefly reviewed to help establish a common method of latency definition and measurement.

2.1 Time Delay Sources

A system, which reproduces the exact form of an input after a specific interval of time, is defined as a time delay. Pure time delay (τ) is a digital system effect. Examples of pure time delay sources[2] are: 1) Computational delay; 2) Loitering delay; 3) Synchronization delay (e.g., "periodic delay"[3]); and, 4) Sampling delay. In a frequency domain analysis, time delay adds phase lag (ϕ) proportional to the input frequency (ω), as $\phi = 57.29\tau\omega$, where τ is in seconds and ω is in units of radians/sec.

The total latency or lag in a visionics device is not just from digital delay. Latency is created from a multitude of sources, most of which are not typically thought of as "pure" digital time delays but most of which add significant, if not the majority, of the total system latency. One such source of latency is caused by dynamic elements in the computational path. A prime example would be the filtering of a head-tracker signal. While the filters attenuate noise in the head-tracker signal, the undesirable side effect is the addition of phase lag, which manifests itself as latency.

Two latency measures have been developed and are accepted as standards because they are reliable, sensitive, measurable, and valid: "equivalent time delay" and "effective time delay."[2]

2.2 Equivalent Time Delay

Equivalent time delay ($e^{-\tau_e s}$) is measured by comparing the frequency response of a (visionics) device against a desired system output. Phase lag greater than the "desired" system is considered to be the "equivalent time delay" (Figure 1). For the analysis of a visionics device, the desired system response is unity amplitude magnification (0 dB) and zero phase lag; that is, the visionics device should neither delay nor distort the sensed image. Thus, equivalent delay measurement for the vast majority of visionics device applications is strictly a measurement of the phase lag between the system excitation and the visionics device output or image.

2.3 Effective Time Delay

Effective time delay ($e^{-\tau_{eff} s}$) provides, in most situations, the time-domain analogy to "equivalent time delay". Effective time delay is computed from a time history of the system output to a sharp, abrupt system input, such as a step input. The effective delay is calculated from the time difference between the system input and the maximum slope intercept of the system output. An example is shown in Figure 1 where the system input is pilot's lateral control input and the output is the aircraft roll rate (p).

2.4 Update Rate

Update rate is a digital system effect. The update rate *does contribute* to the latency (as noted in the digital delay source examples above), however, update rate, by itself, *does not define* the total system latency.

Update rate, somewhat independent of the latency that it contributes, can be a powerful determinant in system usability because if it is not fast enough, the visionics device image will contain noticeable discrete steps or jumps. The effective update rate should nominally be considered the rate of the slowest component in the path between visionics input and output.

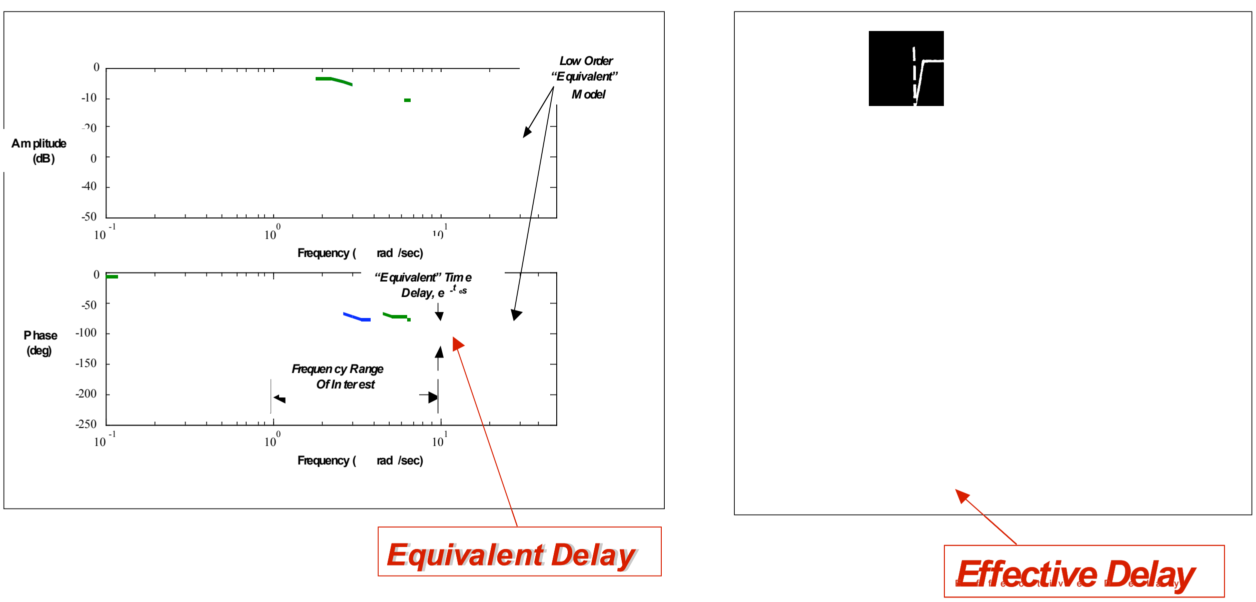

Figure 1: Equivalent and Effective Time Delay Computation Examples

3.0 LATENCY MEASUREMENTS IN VISIONICS DEVICES

While the latency of the visionics device in isolation is important, the total system delay from the time that emitted or reflected energy from the object is sensed in the outside world until that object is represented on a cockpit display is what's critical to mission success. This total latency includes, not just the visionics device latency, but also any delay due to filtering, image processing, display generation, communication, transport delay, etc. Methods to measure the total system latency and requirements for total system latency are presented in the following.

3.1 Measurement

As in any measurement process, accuracy, precision, sensitivity, and repeatability are important parameters to consider in establishing the test methods. Additional influences are the cost, complexity, and finally, the prevention that the measurement process itself doesn't change the system being measured. For example, special visionics device software to facilitate a test should not be used since unique code may not produce representative results of the in-use system.

Where possible and practical, both equivalent (frequency-domain) and effective (time-domain) time delay measures should be used in the analysis of visionics latencies to ensure reliability and repeatability. The two measures should yield the same numeric result for *linear* systems. Consequently, when both equivalent and effective time delay measures are used, the presence of significant numerical differences will be indicative of nonlinear systems or of systems which are frequency-tailored, such as those that attempt latency "compensation" or "prediction". The two measures can thus "flag" a system which uses these techniques and help explain possible problems with their use.[4, 5, 6, 7]

Some methods for measuring video system and Helmet-Mounted Display (HMD) latencies have been developed and may be applicable, in addition to the methods outlined below.[8, 9, 10, 11, 12]

3.2 Fixed View EVS Latency Measurement

One straight-forward method of latency measurement is created from comparative measures by simultaneously recording the visionics device output (e.g., a HUD) and the external scene (Figure 2) and using a moving target as an excitation source. While straight-forward, the methodology requires:

- Synchronized, time-stamped video with sufficient precision to make meaningful delay calculations.
- A target sufficiently visible in both of the recorded (visual and visionics) images.

The most difficult process is typically the generation of target movement to obtain the measurements.

- Some methods have used a rotating radar-reflector or infrared source to create a "light-house" effect. In these cases, the input excitation is absent when the reflector/source is pointed away from the visionics device. When the source is pointed towards the visionics device, a pulse-function is generated. The total delay is measured by the difference in time for the input excitation to appear in the two different recordings. Variations in the rotational rate of the target can provide identification of frequency-banded or aliasing effects. This technique measures the total effective delay.
- Another technique would be to create a controllable oscillatory target – i.e., the visionics equivalent of a metronome (a device that produces a regular, repeated pattern). Using this excitation and measuring the position of the target (in pixels) between the recorded visual image (input) and the

recorded visionics image (output) can provide a frequency response measurement of the visionics system. Commercial off-the-shelf software can be used to track the target and generate time histories of the target positions to facilitate data analysis.

- It is possible, but probably not as pragmatic, to perform the same measurement process in-flight, but by oscillating the aircraft and using a distant, stationary, and distinctly visible object as the target. The problem with this technique is that very high aircraft angular rates and accelerations are required to achieve sufficient target displacement between the recorded visual and visionics images. For instance, HUD latency for a modern fighter aircraft was measured using a HUD camera as it performed constant 200^{+} deg/sec rolls. Using this method, the displacement between the true and HUD-drawn horizon (zero pitch reference line) could be distinguished. A latency of approximately 100 msec was consistently and reliably computed which matched expectations from an engineering analysis of the HUD avionics architecture.

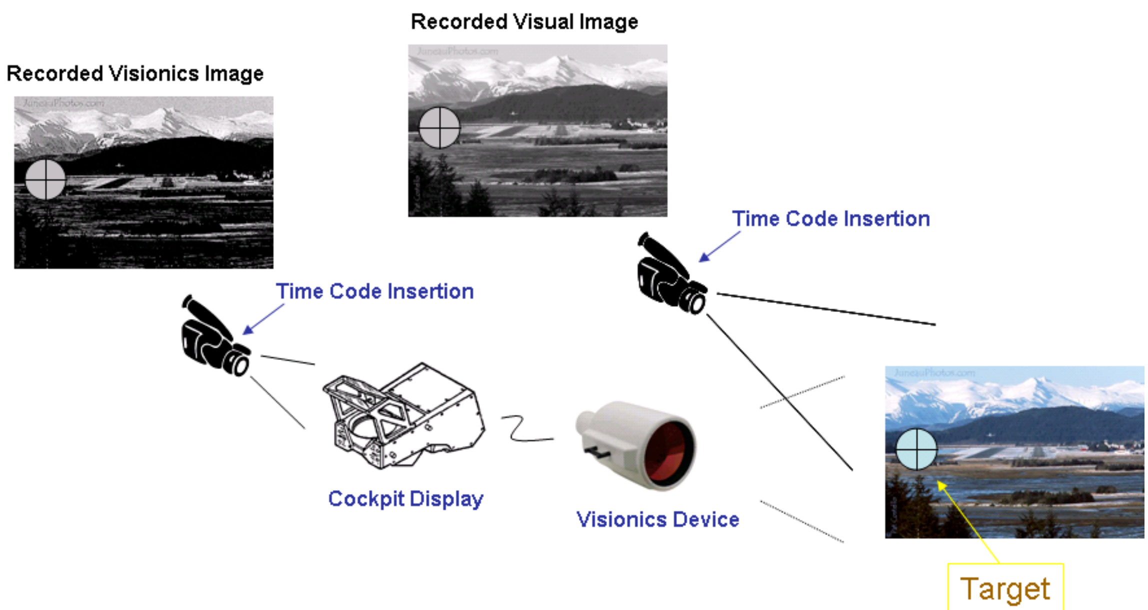

Figure 2: Latency Measurement by Video Comparison

In-flight recording of the cockpit displays, particularly the Head-Up Display, can be difficult because of its small viewing volume. Recording of the actual image is critical, however, to get valid time delay measurements. Fortunately, the latest video equipment is now small enough where direct imaging of the HUD is quite feasible, as shown in Figure 3. The HUD camera, only 7 mm in diameter, is mounted on a mounting arm off of the HUD combiner mount which swings into and out of the HUD viewing volume. While the HUD camera is installed fairly close to the pilot, it does not significantly obscure the pilot's HUD view. This camera records the visionics image to the pilot for comparison to a separate out-the-window video camera.

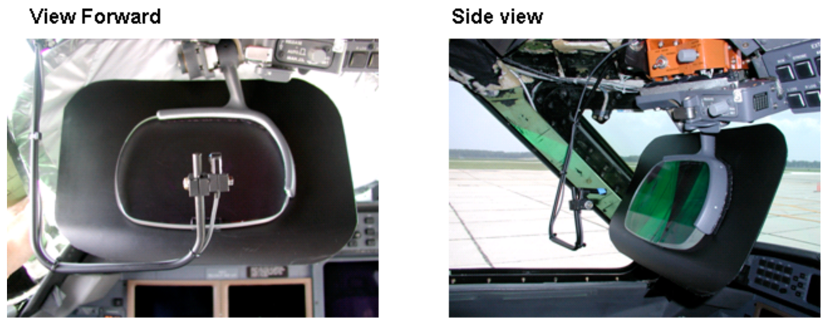

Figure 3: HUD Camera Installation with Vision Restriction Device Installed

3.3 HMD Latency

The visionics delay for Helmet-Mounted or Head-Worn displays can be problematic. Fortunately, an easily administered in-situ latency measurement technique, such as a "windshield washer" test, can be used for HMD latency measurement.

To measure the latency of a head-tracker and symbology generation system, this test involves a space-stabilized, boresight symbol and a "target box" of known dimensions physically located (symmetrically) at a known angular displacement on both sides of the boresight. In the presence of HMD tracker or symbology generation latency, the boresight symbol cannot remain perfectly space-stabilized. The test (Figure 4) requires that the user smoothly oscillate their head in azimuth (or elevation) at a rate which causes the space-stabilized symbol to touch the outer, target boxes. The head-movement rate data divided by the size of the target box, defines the equivalent time delay (at one frequency). (Note that the latency in the head movement data is immaterial to this computation; only the average rate is needed for the equivalent delay calculation.)

While automatic methods to make these measurements are desired for repeatability of results, a user can be easily trained to obtain this data. The distance between the target boxes should be varied to test for linearity (i.e., by requiring different oscillation frequencies) and frequency-tailoring effects.

4.0 LATENCY REQUIREMENTS IN VISIONICS DEVICES

4.1 Pilot-Vehicle Dynamic System

To understand the effect that time delay or latency will cause, a thorough engineering analysis of the pilot-vehicle dynamic system[13] is necessary. This tried-and-true framework allows the evaluation and interpretation of the data and technologies as they influence "the ease and precision with which a pilot performs the tasks required in support of an aircraft role."

From an analysis of visionics systems data using the pilot-vehicle dynamic system, the allowable visionics latency is shown in the following to depend upon: a) the piloting task or operation for which the display device is used; b) the role of the visionics image in the completion of this mission/task (i.e., its "intended function"); and, c) the characteristics of the visionics display device such as its field-of-regard, resolution and field-of-view.

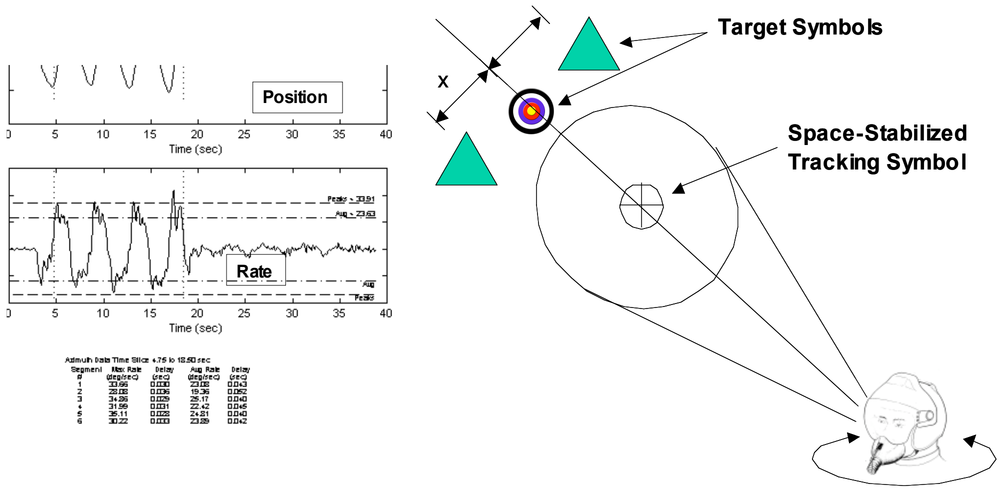

Figure 4: In-Situ HMD Latency Test Example

4.2 Allowable Latency

The visionics device creates a pictorial representation of the external scene for the pilot. This image will be presented on head-up, head-down, and head-worn displays. In the event of impaired (e.g., night) or non-existent outside visual cues (e.g., weather), the ability of the pilot to complete a task is critically dependent upon the cockpit display information; thus, the fidelity of the visionics devices drives the performance of the pilot-vehicle dynamics system and the workload/situation awareness of the pilot. Also, symbology may be used on these displays to complement and enhance this imagery as well as provide critical navigation and guidance information.

4.2.1 Piloting Task/Mission

The criticality of the visionics image and the allowable latency is dependent upon the piloting task/mission demands. The higher the task demands, the smaller the tolerable latency. For tasks which are precisely defined and time-critical, the presence of latency will require greater compensation on the part of the pilot to achieve satisfactory performance. Too much latency can cause closed-loop instability as it naturally follows that the required task performance standards drive the closed-loop system performance.[2]

4.2.2 Role of Visionics Image in Piloting Task/Mission

In concert with the required piloting task, the allowable visionics latency depends upon the role of the visionics device (i.e., its "intended function") in the piloting task/mission. Symbology which is added to the visionics image may influence the latency requirements as it can dictate this role. For example, using FAA definitions from AC-29-120A, a visionics device for the approach, landing, and take-off flight phases can be generally considered as performing one or more of the following intended functions. These are listed in increasing order of the magnitude within which the visionics device plays in task performance and the attendant criticality to the pilot:

- Independent Landing/Take-off Monitor: A generally accepted use of visionics devices would be that of an "Independent Landing / Take-off Monitor" whereby the visionics device, such as a millimeter wave radar-based sensor, is used to present a perspective display of a runway to a pilot on an electronic flight deck display during approach and/or take-off, to independently monitor another type of NAVAID sensor (e.g., Instrument Landing System).

- Obstacle detection: In a similar vein to an independent monitor, the visionics devices may provide an additional layer of runway clearance / obstacle detection, independently again, from established FAA airport procedures which (are supposed to) ensure clear runway operations and maintain aircraft separation.
- Required Visual References: As recently approved under FAA rule making (under FAR Part 25 Section 91.172c), an Enhanced Vision System (i.e., a visionics device) can be used for identification of the runway approach and landing area which must be in view for sufficient time for the pilots to make an assessment of the aircraft's position and rate of change of position, in relation to the desired flight path.
- Visual Guidance: Guidance provides the primary reference for aircraft control or flight path assessment. In the case of Visual Guidance, the visionics device provides real-world cues/information from which the pilot derives these guidance references as if the pilot was flying visually in VMC. Visual guidance is distinguished from guidance symbology where guidance symbology is an explicit symbolic reference such as a HUD flight path marker generated independently from the visionics device.
- Command Information: Command information directs the pilot to follow a course of action in a specific situation (e.g., Flight Director). In the case of a visionics device, however, this command information would be derived from the visionics device. For example, a terrain database, coupled with a forward-looking sensor, might be used to identify obstacles or terrain elevation. This information would be used to define a path providing maximum terrain and obstacle clearance which would then be processed into steering commands for the pilot.

4.2.3 Allowable Latency for Visionics as Situational Information

In most visionics applications to date, guidance and command information has been provided by symbology overlaid on the visionics image where the symbology has been driven primarily from on-board and ground-based sensors, uncoupled from the visionics image. In this way, the command and guidance information is unaffected by the visionics device latency. This is an important distinction in the derivation of visionics device latency requirements.

In an extensive evaluation of enhanced vision systems (EVS) capabilities for commercial and business aircraft applications (then called Synthetic Vision), the FAA led a team in the flight test of a Forward Looking InfraRed (FLIR) and Millimeter Wave Radar (MMWR) system installed on a Gulfstream-II aircraft. The EVS imagery was shown on the HUD for the intended functions of independent landing/takeoff monitor, obstacle detection, and required visual references. The EVS latency was reported to be "200 msec in stable conditions" but increased to 400 msec "when turbulent conditions challenged the image processing."[14] Despite the magnitude of this latency, no control problems were noted, although higher pilot workload was reported. The image latency was obvious to the pilots, and had marginal pilot acceptance.[15] The degree to which this latency was acceptable is likely due to the presence of HUD symbology, which provided the Evaluation Pilot (EP) with guidance and raw data (deviation) information, (presumably at a nominal HUD latency no more than 100 msec). The EVS imagery in this case was "situational information". In this sense, the EP was not "closing-the-loop" directly on the visionics imagery. The EP was using the command and guidance information provided by HUD symbology for this purpose and cross-checking the visionics image to meet the aforementioned intended functions.

Similarly, when tasks require less precision or time-criticality, the pilot can relax their control inputs since a high level of system performance is not required. Consequently, latency effects are significantly reduced. In a power approach task, in simulated instrument conditions, there was no effect on flying qualities for up to 300 msec data added to a head-up display which used a synthetic runway symbol (i.e., a visionics device). While the EP was "closing-the-loop" directly on the delayed HUD imagery, the task demands were low; hence, control problems were not noted in smooth air conditions. However, when turbulence was present, slightly higher task demands to maintain control were generated, and flying qualities, due to the delay in HUD information, were degraded.[16]

Ground simulation research (without motion) on latency effects in primary flight displays showed task performance and pilot workload degradation, although shallow, was observable with increasing display delay.[17] These trends were supported by increased stick activity and degraded tracking performance. The United States Navy established 150 msec as the maximum allowable display latency for all basic flight information.

These data show that visionics latency requirements are not very stringent when the visionics image is used for situation information and symbology provides the command or guidance information. Total system latency of 150 to 250 msec is tolerable in landing approach tasks where symbology is providing the primary flight guidance and command information.

A lack of prominent visual display latency effects for these HUD applications stems from the small visual extent of the displays. Human perception of motion is derived predominately from vestibular senses and peripheral vision cues.[18] Vestibular motion cueing is the most direct and accurate cue for "high frequency" motion effects, with peripheral visual cueing providing supplement motion cueing (albeit delayed and degraded in comparison to vestibular sensing) and spatial orientation. Foveal visual cues provide predominant attitude information but are relatively poor rate of motion sensors. A limited field-of-view HUD or primary flight display provides status information in the foveal area which are important to "higher-level" cognitive task decisions, but they do not provide the more powerful peripheral cues which are a significant component of a human's orientation cues (similar to vestibular and otolith functions) that the pilot needs for aircraft control. Thus, latency in small foveal displays does not impact the high frequency vestibular and peripheral cues that the pilot will predominately use for motion control. HMD studies have substantiated these findings in that a wide field-of-view display provides more stimulation and results in a more compelling display of motion.

4.2.4 Allowable Latency for Visionics as Command/Guidance Information

In contrast, non-empirical evidence suggests that the latency requirement for a HUD/visionics device in a sole-source guidance or command information application may be much more stringent. However, there is little or no experimental evidence and data to support this suggestion.

It would also appear that a bench-mark task for fixed-wing applications of sole-source visionics guidance or command information would be the rejected takeoff. As stated in AC-120-28 (Appendix 2: "Airworthiness Approval of Airborne Systems used during a takeoff in low-visibility weather conditions"):

- "In the event that the airplane is displaced from the runway centerline at any point during the takeoff or rejected takeoff, the system must provide sufficient lateral guidance to enable the "pilot flying" to control the airplane smoothly back to the intended path in a controlled and predictable manner without significant overshoot or any sustained nuisance or divergent oscillations."

- Further, the FAA has deemed that "systems which display only lateral deviation as a cue from centerline tracking have not been shown to provide adequate information for the Pilot-Flying (PF) to determine the magnitude of the required directional correction. Consequently, with such displays, workload and pilot compensation are considered excessive."

This task, using a visionics device to generate guidance and command information, should be a worst-case scenario and drive the latency requirement for visionics device used as sole-source command or guidance information. Experimental data to determine the visionics latency requirement using this task should be generated.

4.2.5 Visual Cue Influence on Latency Requirement

The allowable latency in visionics has also been shown to depend upon the display device field-of-regard, its resolution, and field-of-view.

As a HUD or HMD subtends a significant peripheral FOV, the visionics device will tend toward the generation of a vection response (i.e., visually induced perception of self-motion) and visionics latency may generate a significant visual-vestibular conflict.

Significant visual-vestibular conflicts degrade or cause maladaption of the vestibulo-ocular reflex or the opto-kinetic reflex.[19] (The vestibulo-ocular reflex generates compensatory eye movements based on vestibular senses to keep the gaze stable in space. The opto-kinetic reflex signals head motion and generates compensatory eye movements as an image of the world moves across the retina. Vestibulo-ocular reflex is dominant at high frequencies; opto-kinetic reflex dominates at low frequencies and modest head motion velocities.) Visual-vestibular asynchronization or cue conflict has been found to be a contributor to simulator sickness; however, this is not the only factor. Other visual cue factors may be as or more critical, for instance, display resolution, scene content, depth perception, user experience/background, etc.

Nonetheless, as visionics devices are trending toward higher resolution and field-of-view, the potential of visual-vestibular conflict to create simulator sickness effects dictate the maximum acceptable latency of only 20 msec for usability and performance.[20] Others have concluded that the HMD latency requirements are: 50 msec preferred, 100 msec marginal, 150 msec unacceptable[21]. However, the visual acuity of the HMD in this latter test did not approach "eye limiting resolutions"; hence, lower pilot-task demands were evident and the evaluation pilots noted a tendency to modify their head movements because of the latency. For commercially- or militarily-viable visionics applications, the use of an HMD must not affect normal piloting operations.

Head-up displays of sufficient field-of-view to generate a peripheral vision/vection response have not been developed to date. In this case, visual-vestibular conflict is not a factor. Accordingly, this requirement targets HMD applications.

4.2.3 Noise and Latency Tradeoff in Head-Tracked Visionics

In head-tracked visionics applications, an omni-present tradeoff in performance occurs between visionics image stability and latency. Noise in the head-tracker position determination will cause the visionics output and symbology to jitter. The addition of head-tracker filtering will reduce the jitter but now the phase lag of the filter will increase the system latency. Hence, the visionics image and symbology will be degraded by latency.

In an in-flight evaluation of a Virtual HMD concept,[22] latency was a particular point of emphasis in the system design. Unfortunately, the head-tracker system contained a peak-to-peak maximum noise level of ±4.1 mrad. This noise created noticeable and unacceptable jitter in the aircraft- or space-stabilized symbology. A novel digital filtering scheme was developed to provide noise attenuation for slow head-movement angular rates (presumably when the pilot was holding their head still to designate ground targets or view symbology) and a minimum filtering to create low latency values for higher head-movement angular rates. The resulting latency was a function of head-rate as shown in Figure 5. With these relatively low latency values, only 3 pilots rated the 'best' system latency levels as unacceptable. However, there were a number of comments throughout the post-test questionnaires and during the flights that suggest, although acceptable, any level of system latency is undesirable. On most flights, pilots referred to some degree of symbology movement due to latency effects. Head-tracker noise was still an issue despite the filtering logic.

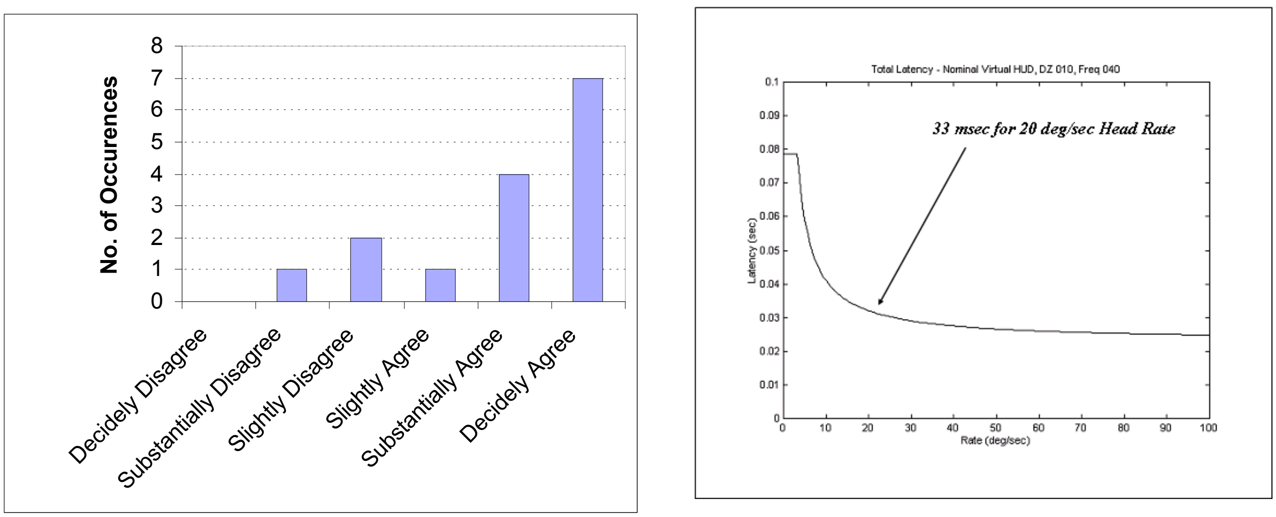

Figure 5: HMD Latency and Acceptability Data

4.3 Update Rate Requirements

Update rate can be a powerful determinant in system usability because if it is not fast enough, the visionics device image will contain noticeable discrete steps or jumps.

A minimum of 15 Hz is recommended for commercial Head-Up Displays[23] but other works show that this may be very optimistic.[16] In addition, a 15 Hz update will cause a minimum of 100 msec system latency due to one-half the update rate for a sampling delay of the input and 67 msec computational delay if only one computation cycle is necessary to compute and display the system output from the input.

For head-tracked visionics, update rates are particularly critical. Pilot head movements can cause very distinct and objectionable jumps in imagery due to update rate effects. For example, when a pilot moves his head at a rate of 15 degrees/sec (Category 2, 10% & 90% percentile values from Reference 24), a 60 Hz update will cause 0.25 degree steps (5 mils) in the visionics imagery. Jitter of 5 mils was shown to be unacceptable.[21]

Although 60 Hz has been used many times as the minimum allowable, higher rates will be necessary to meet acceptable image stability. For a 20 msec total latency as recommended above, update rates approaching and exceeding 240 Hz will be required.

5.0 CONCLUDING REMARKS

A visionics device creates a pictorial representation of the external scene for the pilot. The ultimate objective of these systems may be to electronically generate a form of Visual Meteorological Conditions to eliminate weather or time-of-day as an operational constraint and provide enhancement over actual visual conditions where "eye-limiting" resolution may be a limiting factor. Empirical evidence has indicated that the total system delays or latencies including the imaging sensors and display systems, can critically degrade their utility, usability, and acceptability. Definitions and measurement techniques are offered herein as common test and evaluation methods for latency testing in visionics device applications.

Based upon available data, very different latency requirements are shown based upon the piloting task, the role in which the visionics device is used in this task, and the characteristics of the visionics cockpit display device including its resolution, field-of-regard, and field-of-view. The least stringent latency requirements will involve HUD applications, where the visionics imagery provides situational information as a supplement to symbology guidance and command information. Conversely, the visionics system latency requirement for a large field-of-view Head-Worn Display application, providing a Virtual-VMC capability from which the pilot will derive visual guidance, will be the most stringent, being a value as low as 20 msec.

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