Comprehensive Visual Field Test & Diagnosis System in Support of Astronaut Health and Performance

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In Memoriam: Neil Alden Armstrong (1930 – 2012)

Abstract—**Long duration spaceflight, permanent human presence on the Moon, and future human missions to Mars will require autonomous medical care to address both expected and unexpected risks. An integrated non-invasive visual field test & diagnosis system is presented for the identification, characterization, and automated classification of visual field defects caused by the spaceflight environment. This system will support the onboard medical provider and astronauts on space missions with an innovative, non-invasive, accurate, sensitive, and fast visual field test. It includes a database for examination data, and a software package for automated visual field analysis and diagnosis. The system will be used to detect and diagnose conditions affecting the visual field, while in space and on Earth, permitting the timely application of therapeutic countermeasures before astronaut health or performance are impaired. State-of-the-art perimetry devices are bulky, thereby precluding application in a spaceflight setting. In contrast, the visual field test & diagnosis system requires only a touchscreen-equipped computer or touchpad device, which may already be in use for other purposes (i.e., no additional payload), and custom software. The system has application in routine astronaut assessment (Clinical Status Exam), pre-, in-, and post-flight monitoring, and astronaut selection. It is deployable in operational space environments, such as aboard the International Space Station or during future missions to or permanent presence on the Moon and Mars.**

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1. INTRODUCTION

Long duration spaceflight, such as for and during a permanent human presence on the Moon and future human missions to Mars, will require autonomous medical care to address both expected and unexpected risks. Vision is the primary sense used by astronauts, and visual information is essential during critical phases of spaceflight. The spaceflight environment has significant influence on the visual and ocular system that can adversely affect astronaut performance, and may lead to long-term health consequences.

We present an integrated, non-invasive, comprehensive visual field test & diagnosis system [1, 2] for the identification, characterization, and automated classification of visual field defects caused by the spaceflight environment. This system will support the onboard medical provider and astronauts or crewmembers on space missions with an innovative, non-invasive, accurate, sensitive, and fast visual field test, a relational database for examination data, and a software package for the automated analysis [3] and diagnosis of visual field defects [4, 5]. The system will be used to detect and diagnose conditions affecting the visual field, while in space and on Earth, permitting the timely application of therapeutic countermeasures before astronaut health and performance are impaired.

The paper is subdivided into the following sections:

Section 2: description of hazards to astronaut or crewmember health during spaceflight, affecting vision;

Section 3: description of vision assessment technology underlying the comprehensive visual field test & diagnosis system;

Section 4: description of integrated, automated visual field data analysis;

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Section 5: application potential of comprehensive visual field test & diagnosis system to human spaceflight and presence on another planetary body;

Section 6: discussion and outlook.

2. VISION HAZARDS OF HUMAN SPACEFLIGHT

Vision is the primary sense used by astronauts, and visual information is essential during critical phases of spaceflight, such as launch, entry and landing, rendezvous and docking, robotic operations, and spacewalks. These rigorous vision demands result in 63% of pilot astronauts and 70% of mission specialists requiring vision correction [6]. As such, vision is a key medical criterion for acceptance to the astronaut corps. The spaceflight environment (including human presence on planetary bodies such as the Moon and Mars) and training environments have significant influence on the visual and ocular system that can adversely affect astronaut performance, and may lead to long term health consequences such as intracranial hypertension, ocular hypertension and glaucoma, cataracts, macular degeneration, retinal migraine, retinal detachment, and blindness.

A recent review of active astronaut data [7] revealed the occurrence of the following ocular problems: cataracts, ocular hypertensives, glaucoma suspects, retinal detachments, retinal drusen, retinal degenerations, and hypertensive retinopathy. Ocular/retinal disease exists in the astronaut corps. Post-flight shuttle and International Space Station (ISS) mission interviews indicated 34% of astronauts experienced vision changes during missions. Visual effects, such as decreased acuity, have been documented in long duration International Space Station (ISS) astronauts, and were first noted in 2005. Half of long duration astronauts report a subjective degradation in vision, primarily increasing farsightedness. One case had visual field loss (scotoma) in flight. As of June 2012, fifteen U.S. ISS long-duration spaceflight astronauts have developed some or all of the following findings: hyperopic shift, choroidal folds, cotton wool spots, globe flattening, and/or optic disc edema (papilledema) [8, 9]. These changes have been called the visual impairment/intracranial pressure (VIIP) syndrome. While the exact etiology is unknown it is important to know during a particular mission if the cause is benign or pathologic. Active pathologic etiologies could be ruled out via active visual field testing during space missions.

Risks to vision during space (spaceflight and ISS) and planetary (Moon and Mars) operations include possible corneal, lens, and retinal damage from UV exposure, retinal thermal damage from excessive visible light and IR exposure and other types of radiation, intracranial and intraocular hypertension from fluid shifts, hypoxia during depressurization prior to spacewalks in a pressure suit, and toxic environmental poisoning (several combustion events have occurred in space, and crews have been exposed to ethylene glycol, Freon, Halon, formaldehyde, lead, cadmium, and chloroform). Moreover, a retinal burn occurred in a space tourist shooting photos of the sun with a telephoto lens (i.e., solar viewing) [10, 11].

Intraocular pressure (IOP) increases in spaceflight, and may be related to cephalad fluid shifts. IOP elevation improves after the first 2 days in orbit, but is still above baseline at landing several weeks later. Intraocular hypertension can lead to the onset of visual field loss. Additionally, certain pre-existing conditions such as optic nerve head drusen may potentiate visual field damage from sustained or transient intraocular pressure rise.

A device called a “Tonopen Intraocular Pressure Device” to assess intraocular pressure is currently being used on the International Space Station. However, the capability of detecting and monitoring the consequent onset of visual field loss due to intraocular and intracranial hypertension is neither addressed by this device nor currently otherwise available. Furthermore, contact tonometers (e.g., Goldmann and Tonopen) and even noncontact tonometers (e.g., airpuff), are not completely accurate as the rigidity of the eyeball and the IOP influence the deformation of the cornea by the tonometers. Further, the contact tonometers (e.g., Tonopen) can only be applied by eye care professionals as they require local anesthesia.

The comprehensive visual field test & diagnosis system presented in the following furnishes an integrated methodology to detect and diagnose the impact of the above-mentioned risks on the ocular and vision systems of crewmembers and astronauts, enabling timely countermeasures. In particular it addresses the detection and diagnosis of trauma and acute medical problems, as well as toxic exposure, impacting the ocular and vision system.

3. 3D COMPUTER-AUTOMATED THRESHOLD AMSLER GRID TEST (3D-CTAG)

We have developed a Web-based, integrated, and comprehensive visual field test & diagnosis system to assess the visual performance of astronauts and crewmembers [1-3]. At the core of the system is the *3D Computer-automated Threshold Amsler Grid* (3D-CTAG) test [12]. In multiple clinical studies 3D-CTAG has proven to be innovative and successful for fast (<5 minutes per eye), easy (intuitive use of finger), accurate (<1 degree spatial resolution), non-invasive, and comprehensive visual field testing. Conditions such as glaucoma [13], ocular hypertension [14], age-related macular degeneration with distinction between wet and dry AMD [15, 16], macular edema [17], ethambutol toxicity [18], anterior ischemic optic neuropathy and optic neuritis [19] have been successfully detected. In addition, 3D-CTAG allows for an unprecedented characterization of the structure of visual field defects in three dimensions [12, 3].

With one eye covered, the subject is positioned at a fixed distance in front of a touch-sensitive computer screen on a head-chin rest (Fig. 1) and finger-traces the areas of an Amsler grid missing from his field of vision (Fig. 2).

Figure 1. Examination station setup at one of six established test sites to date for the Internet-based, comprehensive visual field test & diagnosis system. Each test site is equipped with a standardized set of hardware comprising an Apple Mac mini computer, a head-chin rest, and a touch-sensitive computer monitor.

The Amsler grid [20, 21] was introduced in 1947 and represents a standard means of evaluating the central vision surrounding the fovea (usually central 10 degrees radially from fixation). It is capable of identifying absolute visual field defects (i.e., absolute scotomas) by using an absolute contrast target, i.e., a black grid on a white background. However, the Amsler grid, as originally introduced, is not sensitive enough to detect subtle visual field defects such as relative scotomas. Relative scotomas, as opposed to absolute scotomas, change their size and shape as a function of contrast, and often mark the onset of a disease.

In contrast to the original Amsler grid, 3D-CTAG [12] presents Amsler grids at various degrees of contrast across a visual field area determined by the dimensions of the touch-screen by repeating the test at different grayscale levels, thereby enabling detection of even subtle visual field defects (Fig. 2). Results of the 3D-CTAG test are recorded by the computer in the form of a 3D data array (horizontal location x, vertical location y, contrast sensitivity at (x, y)) and stored in a relational Postgres database (Fig. 3). The 3D data represent the measured contrast sensitivity across the tested visual field. The contrast sensitivity is a functional measure of the performance of the visual system including retina, optic nerve, and visual cortex.

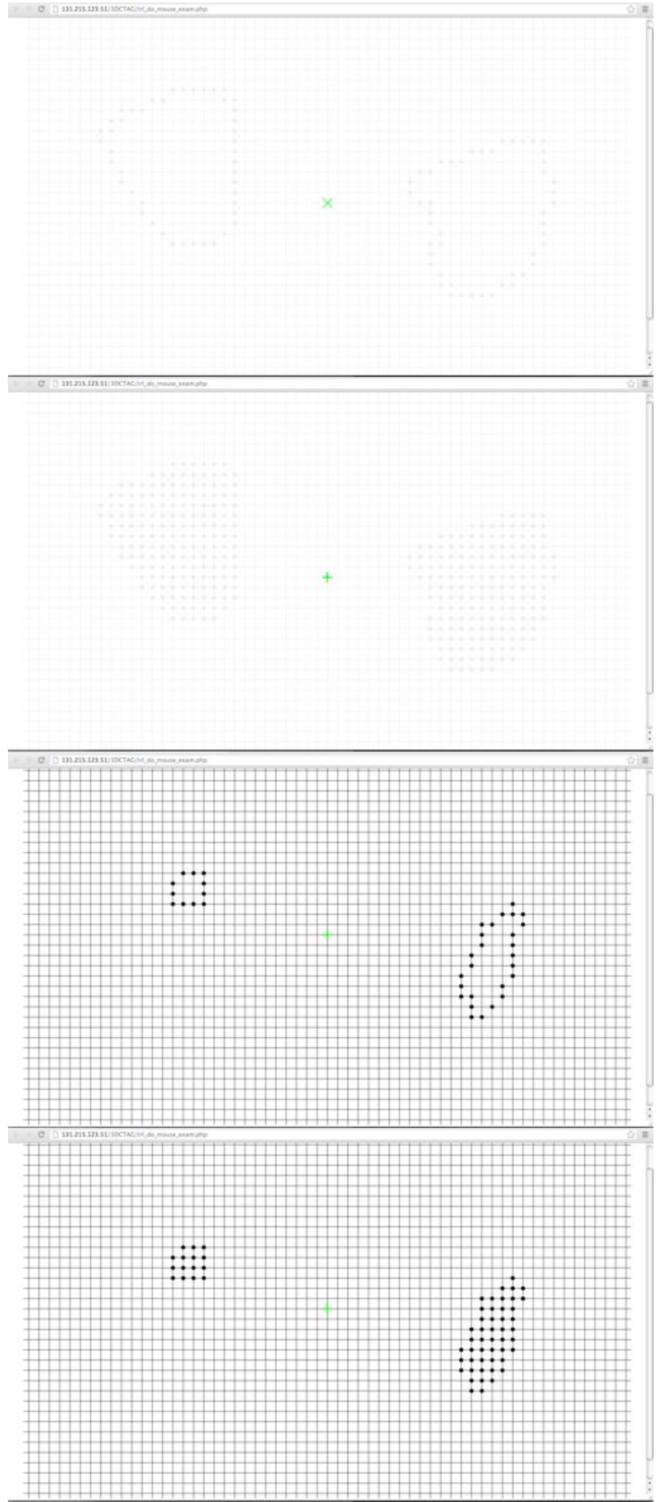

Figure 2. *1st:* Finger-traced outline of visual field missing at low contrast Amsler grid (i.e., harder to see). The green "X" at screen-center is the central fixation marker. *2nd:* Finger-traced areas subsequently filled in as "non visible", i.e., scotoma. The test is repeated at varying degrees of contrast. *3rd:* Finger-traced outline of visual field missing at high contrast Amsler grid (i.e., easier to see). *4th:* The finger-traced areas subsequently filled in as "non visible", i.e., scotoma.

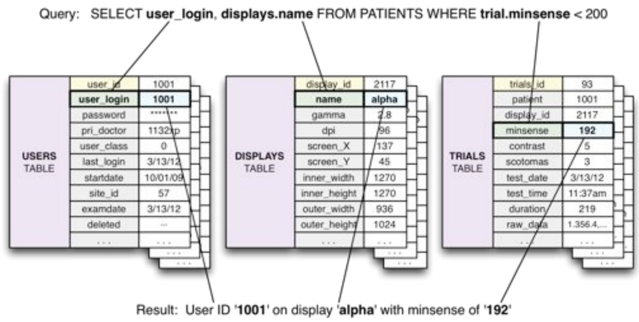

Figure 3. Architecture of a relational Postgres database for the comprehensive visual field test & diagnosis system (after [1]): A database query is depicted that determines if any users have run 3D-CTAG tests with a minimum contrast sensitivity setting of less than 200. The result ('1001' on machine 'alpha' with min_sense of '192') is possible because of the relational nature of the information stored in the database.

Following each test, a 3D depiction of the central visual field (also known as the central "hill-of-vision"), a topographical contour map (isopters), the area of visual field loss as a function of Amsler grid contrast, and the comprehensive visual field and scotoma characterization and classification are automatically generated and displayed onscreen, both numerically and graphically using the freely available Gnuplot© plotting package (Fig. 4). The 3D display alone already allows clinical experts (ophthalmologists and neuro-ophthalmologists) to detect and identify certain eye conditions, and to quantify their time-progression.

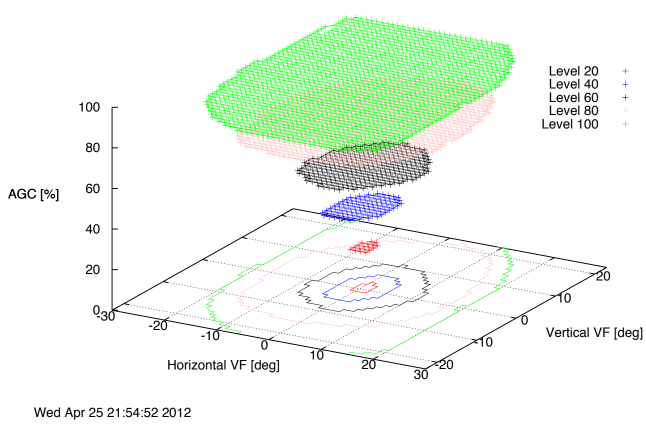

Figure 4. Example 3D visual field plot obtained with 3D-CTAG. The x-axis denotes the horizontal and the y-axis the vertical dimension of the subject's visual field, both measured in degrees from the center of fixation. The z-axis indicates the Amsler grid contrast used for testing. The actual measured contrast sensitivity across the subject's visual field as a function of x, y, and the respective Amsler grid contrast are displayed in color-coded form. A topographical contour map (i.e., boundaries of visual field defects at respective Amsler grid contrast) is displayed in the x-y plane at the bottom of the 3D plot.

4. Automated Visual Field Data Analysis

In the absence of clinical experts (e.g., during spaceflight, onboard the ISS, or at a planetary outpost), an integrated auto-characterization system analyzes 3D-CTAG visual field data and objectively identifies and characterizes the occurring visual field defects (i.e., *scotomas,* as in missing areas of vision) in accordance with the following numerical methods [3]: (1) *visual field data transforms* include area and volume of visual field loss, lost and preserved area grades, and slope distribution; and (2) *scotoma data transforms* include scotoma perimeter/scallopedness and scotoma center location.

To also account for the phenomenon of *metamorphopsia* (i.e., distortion or waviness of straight Amsler grid lines instead of missing ones) we devised and implemented a more general superset of algorithms for the automated characterization of both distorted vision (i.e., *metamorphopsia*) and visual field defects (i.e., *scotomas*) in 3D [2]. In collaboration with ophthalmic experts, we conceived the following objective characterization indices that describe visual field abnormalities [3, 2]:

- *Area of Visual Field Impaired at XX% Contrast:* number of Amsler grid points marked as not visible at a given Amsler grid contrast
- *Absolute Hill-of-Vision Volume Lost:* total number of Amsler grid points marked as not visible across all tested Amsler grid contrasts
- *Relative Hill-of-Vision Volume Lost:* absolute # of test-locations not seen divided by the total # of tested Amsler grid points
- *Lost Area Grade (LAG)/Inverse Lost Area Grade (ILAG):* existing scotoma area at highest/lowest tested contrast level divided by existing scotoma area at lowest/highest tested contrast level
- *Preserved Area Grade (PAG)/Inverse Preserved Area Grade (IPAG):* existing preserved visual field area at lowest/highest tested contrast level divided by existing preserved visual field area at highest/lowest tested contrast level.

These characterization indices enable the qualitative and quantitative analysis of temporal changes of a subject's visual field.

For visual field classification purposes, these indices taken together form a feature vector that is characteristic for a particular 3D-CTAG examination result, i.e., visual field. As a result, visual fields, assessed with the Web-based comprehensive visual field test and diagnosis system, can now be compared to each other via their respective feature vectors, and anomalies can be detected.

The comparison between visual fields and the anomaly detection among a set of visual fields, such as a set of visual fields for a particular subject (i.e., astronaut/crewmember) obtained over time, are being performed by an auto-classification system based on the *Automated Global Feature Analyzer (AGFA)* [5] that was originally developed for the automated classification of planetary geologic field sites, but has been further expanded to be a generically applicable classification tool for any kind of data in feature vector form.

The feature vectors in the case of visual field data classification are comprised of the *relative* characterization indices listed above: relative # of test locations not seen, volume lost relative to hill-of-vision, LAG, ILAG, PAG, IPAG. The reason for the use of relative as opposed to absolute characterization indices for the feature vectors is that the resulting feature vectors are largely independent from the respective visual field examination specifications, such as the area of visual field tested and contrast levels presented. Otherwise a comparison of different visual fields, taken on different test machines with different examination parameter settings, becomes extremely challenging, if not impossible.

In particular the AGFA-core performs the calculation of the following comparative quantities:

- <u>*Overlap Parameter*</u> [4]: defined as the N-dimensional scalar product between two feature vectors, ranging from -1 to +1, with -1 representing the case that two visual fields are completely opposite/dissimilar from each other, 0 representing the case that two visual fields are orthogonal to each other, and with +1 representing the case that two visual fields are the same – and of course all continuous variations in between these values. The Overlap Parameter is a measure of similarity between two feature vectors.

- <u>*Hamming Distance*</u> [4]: defined as the sum of squared differences between the feature vector components, divided by the dimension N of the feature vector. The Hamming Distance is always >= 0 and is a measure of similarity between two feature vectors.

- <u>*Euclidian Distance*</u>: defined as the square root of the sum of squared differences between the feature vector components. The Euclidian Distance is always >=0 and is also a measure of similarity between two feature vectors.

Furthermore, AGFA performs sequential clustering [22] among other clustering techniques to group visual field exams of a subject or of several subjects into clusters of similarity based on the respective feature vectors, and subsequently performs anomaly analyses based on inter-cluster comparisons [5]. An anomaly is defined as a particular feature vector or a component of a particular feature vector (i.e., relative # of test locations not seen, volume lost relative to hill-of-vision, LAG, ILAG, PAG, IPAG), which is significantly different from the other feature vectors or the same component in the other feature vectors. Together with the Overlap Parameter, Hamming Distance, and Euclidian distance, the clustering and anomaly detection provides a means for visual field classification and comparison. Moreover, this toolset, provided by AGFA [5], allows for the assessment of visual field deterioration or improvement over time by analyzing the underlying feature vectors that represent the respective visual fields at a given time.

The feature vectors can also serve as inputs to artificial neural networks, such as single- or multi-layered perceptron systems, as well as Hopfield attractor networks for the generation of preliminary diagnoses [4]. In particular the adaptation of Hopfield attractor networks to the respective visual field area and geometry being tested on a given examination station/device (Figs. 1 and 5) is straightforward because they make no assumption with respect to the visual field geometry [4].

The fact that *only* the 3D-CTAG-derived visual field raw data, rather than the derived characterization and classification data, are stored in the relational database, enables rapid re-analysis of all stored visual field data with new analysis algorithms as they become available or as they are being refined in collaboration with ophthalmic experts.

5. Application to Human Spaceflight and Presence on Another Planetary Body

State-of-the-art perimetry devices are bulky, thereby precluding application in a spaceflight setting. In contrast, 3D-CTAG requires only a touchscreen-equipped computer or touchpad device, such as an iOS-based handheld (e.g., iPad; Fig. 5 and [2]), which may already be in use for other purposes (i.e., no additional payload), and custom software. The comprehensive visual field test & diagnosis system has application in routine astronaut assessment (Clinical Status Exam), pre-, in- and post-flight monitoring, and astronaut selection. It is deployable in operational space environments, such as aboard the International Space Station or during future missions to or permanent presence on the Moon and Mars. Depending on the urgency of diagnosing a condition affecting the visual performance of an astronaut/crewmember, and depending on the communication bandwidth and delay, the comprehensive visual field test & diagnosis system provides for two distinct modes of operation:

1. *True telemedicine:* 3D-CTAG examination data is sent back to Earth for evaluation and the resulting diagnosis is returned;

2. *Autonomous in-situ:* 3D-CTAG examination data is analyzed by the integrated auto-characterization

system, and visual field defects are objectively identified, characterized, and classified, resulting in a probabilistic diagnosis in the absence of expert input.

Operationally, the impact of the 3D-CTAG examination is minimal. The exam requires less than 5 minutes per eye. Setup and teardown and stowage are projected to take only up to an additional 5 minutes, including turning on the touchscreen device (e.g., iPad or regular touch-sensitive computer screen) and launching the 3D-CTAG software. For use in zero-gravity, the head-chin rest can be rigidly connected to the touchscreen device using a simple mounting bracket with minimal structural interfaces requiring very little set-up. Thus, the entire apparatus would be attached to the subject's head ensuring the proper distance between eye and screen. No special body stabilization would be required beyond common foot-loops. If desired, the screen could also be secured to a convenient spot on the spacecraft interior with Velcro. For reduced-gravity planetary applications, the Velcro could be supplemented by simple mechanical fasteners.

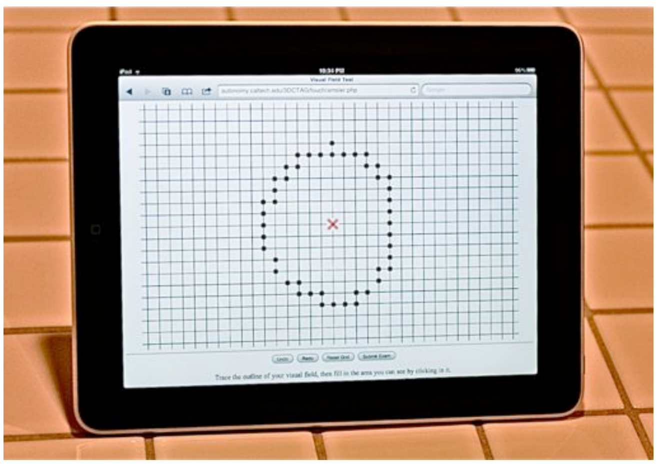

Figure 5. Comprehensive visual field test & diagnosis system administered on an Apple iPad: visual field test session with a black/grey-scaled Amsler grid on a white background.

6. DISCUSSION & CONCLUSIONS

Vision is the primary sense used by people on Earth and in space, and visual information is essential during daily life. There are many conditions that, if undetected or detected too late, may lead to irreversible visual field loss and eventually to blindness. Glaucoma and macular degeneration are the two leading causes for blindness that are currently untreatable. Previous studies using the 3D computer-automated threshold Amsler grid test (3D-CTAG) [12-19], especially with glaucoma suspect patients [14], have demonstrated the effectiveness in detecting and visualizing visual field defects: Scotomas, which are undetectable by state-of-the-art standard automated perimetry ("Gold Standard"), were repeatedly identified by this test early on.

The 3D-CTAG-based visual field test & diagnosis system provides several advantages over state-of-the-art conventional automated visual field testing such as the Humphrey Visual Field Analyzer. It measures a 3D rather than a 2D depiction of scotomas, providing unique insight into visual field defects. The new test also has a superior angular resolution: The 1-degree grid spacing (or less) compared to the typical 6 degrees for state-of-the-art automated perimetry results in an at least 36 times higher spatial resolution, allowing for an unprecedented characterization of the structure of visual fields and scotomas, typical for various diseases, in 3D.

As mentioned earlier, standard perimetry devices are costly and bulky, thereby precluding practical application in operational space environments. In contrast, 3D-CTAG requires only a touch-sensitive computer screen, which may already be in use for other purposes, a head-chin rest and mounting bracket, and the 3D-CTAG software. Finally, state-of-the-art automated perimetry is time consuming – on the order of tens of minutes per eye – making it difficult for frequent use, especially in operational space environments. 3D-CTAG is simple to use and tests are performed quickly (less than 5 minutes per eye), making frequent retesting feasible for subject follow-up over time.

The comprehensive visual field test & diagnosis system provides medical care providers, crewmembers, and astronauts with a non-invasive, accurate, sensitive, and fast visual field test, a relational database for examination data, and a software package of sophisticated analysis and characterization algorithms to help classify and diagnose (1) visual field defects (i.e., *scotomas* as in missing areas of vision), and (2) distorted vision (i.e., *metamorphopsia* as in waviness of straight Amsler grid lines).

The objectively derived visual field, scotoma, and metamorphopsia characterization data will:

- Probabilistically predict ailments via statistical methods and artificial neural networks (3D-CTAG-adapted version of visual field classification neural network described in [4]);

- Indicate both qualitatively and quantitatively temporal changes in visual fields of subjects over time using classification methods derived from autonomous planetary exploration (see Automated Global Feature Analyzer AGFA, [5]).

As such the developed comprehensive visual field test and diagnosis system is capable of:

- Detecting and diagnosing conditions affecting the visual performance of astronauts/crewmembers in situ, allowing for the timely application of therapeutic countermeasures;

- Monitoring the efficiency and efficacy of therapeutic treatment of the condition over time.

The integrated, comprehensive visual field test & diagnosis system [1-5] can be hosted *locally* on a touch-screen-equipped computer (i.e., intranet/standalone application aboard the ISS), or, with Internet access, *centrally* on a server, thus permitting screening and examining subjects on a regional to global scale, i.e., worldwide. Subject examinations can be performed on touchscreen-equipped computers and touchpad devices, such as iOS-based handhelds (e.g., iPad; Fig. 5 and [2]).

The system is currently hosted on three high-end 64-bit servers at Caltech with uninterruptable power supplies, allowing thousands of individuals to access the visual field test & diagnosis system simultaneously from all over the world.

The automated characterization and classification of 3D-CTAG visual field data may assist physicians with an independent second opinion and provide expertise where otherwise not readily available, offering a promising perspective towards modern computer-assisted diagnosis in medicine and telemedicine [2-5], especially in space and other remote settings (e.g., military environments and developing countries).

In summary, long duration spaceflight (e.g., trips to Mars) or a permanent human presence on the Moon and future space exploration missions to and eventual settlement on Mars will require autonomous medical care to deal with expected and unexpected risks. As such the use of expert systems and telemedicine procedures is warranted, especially in light of the communication limitations and the lack of an in-situ clinical support infrastructure.

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BIOGRAPHIES

Wolfgang Fink *is currently an Associate Professor and the inaugural Edward & Maria Keonjian Endowed Chair of Microelectronics with joint appointments in the Departments of Electrical and Computer Engineering, Biomedical Engineering, Systems and Industrial Engineering, Aerospace and Mechanical Engineering, and Ophthalmology and Vision Science at the University of Arizona in Tucson. He is a Visiting Associate in Physics at the California Institute of Technology, and holds concurrent appointments as Visiting Research Associate Professor of Ophthalmology and Neurological Surgery at the University of Southern California. Dr. Fink is the founder and director of the Visual and Autonomous Exploration Systems Research Laboratory at Caltech (http://autonomy.caltech.edu) and at the University of Arizona (http://autonomy.arizona.edu). He was a Senior Researcher at NASA's Jet Propulsion Laboratory from 2000 till 2009. He obtained a B.S. and M.S. degree in Physics and Physical Chemistry from the University of Göttingen, Germany, and a Ph.D. in Theoretical Physics from the University of Tübingen, Germany in 1997. Dr. Fink's interest in human-machine interfaces, autonomous/reasoning systems, and evolutionary optimization has focused his research programs on artificial vision, autonomous robotic space exploration, biomedical sensor/system development, cognitive/reasoning systems, and computer-optimized design. Dr. Fink is a Fellow of the American Institute for Medical and Biological Engineering (AIMBE). His work is documented in numerous publications and patents. Dr. Fink holds a Commercial Pilots License for Rotorcraft.*

Jonathan B. Clark *is currently an Associate Professor of Neurology and Space Medicine at Baylor College of Medicine, teaches at BCM's Center for Space Medicine, and is Space Medicine Advisor for the National Space Biomedical Research Institute. He received a B.S. from Texas A&M and an M.D. from the Uniformed Services University of the Health Sciences, is board certified in Neurology and Aerospace Medicine, and is a Fellow of the Aerospace Medical Association. He was a Member of the NASA Spacecraft Survival Integrated Investigation Team from 2004 to 2007 and the NASA Constellation Program EVA Systems Project Office Standing Review Board from 2007 to 2010. He worked at NASA from 1997 to 2005, was a Space Shuttle Crew Surgeon, and was Chief of the Medical Operations Branch. Dr. Clark served 26 years on active duty with the U.S. Navy and qualified as a Naval Flight Officer, Naval Flight Surgeon, Navy Diver, and Special Forces Military Free-fall parachutist. Dr. Clark is Medical Director of the Red Bull Stratos Project, a manned stratospheric balloon free fall parachute flight test program, which on 14 October 2012* *successfully accomplished the highest stratospheric free fall parachute jump from 128,100 feet, achieving human supersonic flight without an aircraft at 834 miles per hour. His professional interests focus on the neurologic effects of extreme environments and crew survival in space.*

Garrett E. Reisman *is currently the SpaceX commercial crew program manager. Dr. Reisman is responsible for working with NASA to prepare SpaceX's Falcon 9 rocket and Dragon spacecraft to carry astronauts. He was the SpaceX project manager for CCDev2 – a $75 Million partnership with NASA to mature the Dragon Spacecraft launch abort system and crew accommodations. Reisman is now the SpaceX project manager for CCiCap – a $440 Million partnership with NASA to complete the design of the Dragon-Falcon 9 crew vehicle, perform hardware testing, ensure astronaut safety, and pave the way for NASA certification of the vehicle. Reisman came to SpaceX from NASA where he served as an astronaut starting in 1998. He has flown on two space shuttle missions, during which he logged over 3 months in space including over 21 hours of extravehicular activity (EVA) in 3 spacewalks. Dr. Reisman served with both the Expedition-16 and the Expedition-17 crews as a Flight Engineer aboard the International Space Station. Reisman holds a B.S. in Economics and a B.S. in Mechanical Engineering and Applied Mechanics from the University of Pennsylvania, an M.S. in Mechanical Engineering from the California Institute of Technology, and a Ph.D. in Mechanical Engineering from the California Institute of Technology. He is a FAA Certified Flight Instructor.*

Mark A. Tarbell *is currently a Senior Research Scientist at the University of Arizona, a Visiting Scientist at Caltech, and Senior Software Specialist with more than 25 years of satellite and ground-based command and control system architecture design and development. Mr. Tarbell designed and implemented the ground data processor control infrastructure for JPL's SRTM mission, and was involved with JPL's Jason JTCCS project, which supports real-time telecommanding of Earth-orbiting satellites from wireless handheld devices. In collaboration with the Visual and Autonomous Exploration Systems Research Laboratory at Caltech, he recently co-designed and implemented a remote telecommanding control system for an outdoor test bed for autonomous surface exploration, and a biomedical Artificial Vision Support System, which uses various vision processing algorithms to interface to blind patients' implanted retinal microelectrode array in real time.*