Phase I Project Summary

Firm: Intelligent Automation, Inc.
Contract Number: NNX12CF13P
Project Title: Non-intrusive Hazardous Pilot Cognitive State Assessment via Semi-Supervised Deep Learning: CSA-Deep

Identification and Significance of Innovation: (Limit 200 words or 2,000 characters whichever is less)
To improve aviation safety, it is critical to non-intrusively monitor crew members and predict hazardous cognitive states to design effective mitigation strategies in current aviation and Next Generation Air Transportation System (NextGen).

Although a plethora of research work has been devoted to Cognitive State Assessment (CSA), there are three major challenges in developing in-flight cognitive state assessment for crew members. **First**, limited research has been conducted on monitoring multiple cognitive states simultaneously**Error! Reference source not found.**, especially with a single model. **Second,** there are huge amounts of unlabeled training data (without being associated with cognitive state for each measurement), whereas data with labels provided by subject matter experts manually or via sporadic and intrusive self-reporting (such as the NASA TLX for workload and SART for Situation Awareness) is far and few between due to time/budget constraints and other practical concerns. This presents a difficult problem when applying any supervised machine learning algorithm, which requires all sensor data to be labeled. **Third**, large individual variations exist in the sensor data and most of existing cognitive state assessment tools do not work well because of their limitations in accounting for the considerable individual differences in responses to task schedule, individual fitness (sleep loss, anxiety) and environmental changes.

Technical Objectives and Work Plan: (Limit 200 words or 2,000 characters whichever is less)

Objective 1: Enhance the CSA-Deep architecture.
Objective 2: Evaluate the CSA-Deep performance
Objective 3: Develop full-fledged software tool
Objective 4: Develop relationships with industrial partners for technology transition.

To meet the Phase II objectives, we will perform the following tasks.

- **Task 1 - Refine requirements for the hazardous cognitive state assessment system.**
- **Task 2 - Enhance the CSA-Deep Architecture**
  - **Task 2.1 – Build a committee-machine based on multiple deep structures**
  - **Task 2.2- Enhance deep learning to address hazardous cognitive state assessment of an individual**
  - **Task 2.3 – Improve multi-task learning capability by considering intrinsic relatedness related among tasks based on trace norm regularization**
  - **Task 2.4 – Improve CSA using non-intrusive head motion features**
- **Task 3 –Perform small scale crew coordination experiments**
  - **Task 3.1 –Refine experiment design**
  - **Task 3.2 –Perform data collection to investigate crew coordination**
- **Task 4 – Implement CSA-deep on GPUs.**

- **Task 5 - Performance evaluation using benchmark datasets via comparative studies**
- **Task 6 –Develop the CSA-Deep software and perform software testing**
- **Task 7 - Integrate the CSA-deep cognitive state assessment module with CATS and package/document the software package for NASA usage**
- **Task 8 - Develop relationships with industrial partners to commercialize the technology.**

Technical Accomplishments: (Limit 200 words or 2,000 characters whichever is less)

The focus of the Phase I program was to demonstrate the feasibility of the proposed Cognitive State Assessment via Deep Learning (CSA-Deep) technique for the assessment of multiple hazardous cognitive states in order to predict and prevent performance decrements. Three key achievements have been made in Phase I.

First, a deep learning based model for simultaneous assessment of multiple cognitive states was developed. As a state-of-the-art semi-supervised machine learning technique, deep learning has three unique features: semi-supervised learning with a deep structure, better regularization and faster convergence, simultaneous multiple cognitive states assessment and model individualzation. We evaluated the performance using the Boeing 737 flight simulator data previously collected under NASA contract # NNX10CB27C. With 3% of labeled data for fine-tuning, the performance is better than the performance achieved without pre-training (87.9% vs. 83.9%, p=0.0152).

Second, we investigated the effectiveness of non-intrusive sensors, head motion extracted from the eye tracking data more specifically, for cognitive state assessment, and the results are promising. For example, the mean arraucy tested with 16 pilots is 94.6% with a model trained with only 10% of data, which is significantly better than that achieved with EEG signals (87.9%, p=0.008).

NASA Application(s): (Limit 100 words or 1,000 characters whichever is less)

We will work closely with NASA to ensure that technology developed in this effort can be integrated with the NASA's systems, reducing risk associated with technology transition. The proposed innovation has applicability to research work in the Robust Interfaces to Trajectory Automation (RITA) element within NASA's Safe Flight Deck Systems and Operations (SFDSO) sub-project within the Aviation Safety Program (AvSP) Vehicle Systems Safety Technologies (VSST) Robust AutomationCrewSys (ACS) program as well as potential for enhancing safety through crew coordination in other manned aircraft and spacecraft work.

Non-NASA Commercial Application(s): (Limit 200 words or 2,000 characters whichever is less)

Air combat planning systems (Air Force, Navy): There is sustained demand for trainers and planning systems used for mission planning. In addition, the success of UAVs is leading to increased demand for trained UAV operators in the military. The CSA-Deep (in conjunction with IAI's air traffic models) can be used to create simulated mission sorties to enable testing of pilot/UAV operator and Air traffic controller performance under different conditions.

Air Operation Centers: There is significant demand for simulation-based training for air traffic management in military and civilian arenas. In addition, there is an urgent need to train air traffic controllers to replace the large number of ATCs who are approaching retirement age. Furthermore, the gradual rollout of FAA's Next Generation Air Traffic System (NGATS) and its new systems, applications and operational procedures will require the development of new simulation-based training systems.

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