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6. AUTHORS

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14. ABSTRACT

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RPPR Final Report
as of 19-Nov-2018

Agency Code:

Proposal Number: 67242CSREP **Agreement Number: W911NF-15-1-0455**
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DUNS Number: 021551817 EIN: 746001399
Report Date: 30-Nov-2018 Date Received: 16-Nov-2018
Final Report for Period Beginning 01-Sep-2015 and Ending 31-Aug-2018
Title: Tele-presence for Efficient Tele-robotics through Immersive Virtual Reality
Begin Performance Period: 01-Sep-2015 **End Performance Period:** 31-Aug-2018
Report Term: 0-Other
Submitted By: Ph.D Alireza Tavakkoli Email: tavakkol@unr.edu
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Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 2 **STEM Participants:** 1

Major Goals: The proposed project aims to develop a fundamental framework for establishing an immersive virtual reality environment for robust and scalable human robot interaction in a cooperative intelligent architecture. In order to accomplish this objective, we aim to address the following over-arching question: How can we develop a framework capable of merging an artificially intelligent environment with an immersive virtual one, in a manner that both environments become aware of their user's motives and intentions, while drawing the human operator to intuitively engage with the environment and its agents? In order to answer this question, we have designated four main scientific and technical goals:

Goal 1- Developing the cyber-physical-virtual environment for telepresence and telerobotic
Goal 2- Utilizing sensory fusion to facilitate interactivity and breadth of information.
Goal 3- Facilitating immersion and depth of information for tele-presence to help with robotic tele-operation.
Goal 4- Increasing the system efficiency by utilizing distributed and high performance computing.

Our approach and research tasks to achieve the objectives of this project for the integration of an intelligent physical environment with its immersive virtual counterpart encompass the four goals presented above. In the following, an overview of each of the research tasks and their associate objectives accomplished throughout this project are discussed.

To achieve the main goal of this project (Goal 1) we have enhanced the bridge created during the first year of the project between the fields of robotics and digital gaming. This bridge is comprised of three research tasks, of which the first two (VRT-1 and VRT-2) are interconnected. The objective of these two tasks is to help build reliable models in order to facilitate information depth and immersion (human's perception) as well as information breadth and interactivity (system's perception). To approach the issues of breadth of information and interactivity (VRT-1) we rely on robotics and machine learning. This research task addresses Goal 2 above.

On the other hand, we have the problem of the human's perception of the agent's situation and its environmental conditions. This problem is approached from the perspective of the digital gaming field (VRT-2). This research task addresses Goal 3 above. The third research task (VRT-3) in support of this computational platform is to enhance the processing power of the framework and to free on-board computational needs on both robotic agents and the virtual reality components. To achieve this objective, we are studying and developing data parallel algorithms for the data-parallel processes used across the system. This computation targets nVidia's CUDA heterogeneous computing platform and is currently being performed on servers based on NVidia's Kepler architecture; i.e. nVidia K-80 GPUs. This research task addresses Goal 4 above.

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Accomplishments: During the last reporting period we worked in the following research directions:
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Activity 1- Developing an Integrated Immersive Virtual Reality environment for Telepresence and Telerobotics. (Addressing Goal 1)

- Objectives: Develop an enhanced architecture for integrating a virtual environment with a physical one to remotely and effectively operate robotic agents. This environment, termed Virtual Environment for Tele-Operation (VETO) addresses some of the limitations of the previous infrastructure done in Years 1 and 2 of the project. We also evaluated the measure of trust of robots in a controlled human-robot interaction scenario (Ohenhen, 2018).

- Significant Results: During this reporting period we developed an architecture, termed VETO (Virtual Environment for Tele-Operation), comprising of three major components; i.e. virtual reality clients, a centralized High Performance Computing (HPC) computational server, and a number of heterogeneous robotic agents. This framework allows for multiple clients to interact with multiple heterogeneous robots in a virtual environment, with the ultimate goal of remotely operating the agents while allowing for high-fidelity telepresence by the operators (Wilson, 2018) and (Wilson, 2017b). This framework addresses some of the limitations of the previous iteration ArVETO (Bounds, 2016) and (Bounds, 2016a).

- Key Outcomes: The benefits of the new VETO architecture are threefold. First, it provides a robust and multi-platform client-server architecture that doesn't rely on propriety networking frameworks. This architecture is built on the a cross-platform networking infrastructure called Crossock (Wilson, 2017a). In addition, the dedicated server processes data intensive computations needed in support of the entire system; such as visual object recognition, mesh generation, and intent recognition.

Second, the VETO architecture uses UE4 actor replication, to efficiently stream the robots' properties to further reduce the network congestion. Finally, the proposed framework efficiently utilized the concept of network relevancy. That is, each UE4 client in the VETO architecture communicates to the server from which robot, if any, it requests data. This efficient bandwidth utilization is crucial, as all calculations and transactions in the VETO architecture are required to be performed in real-time.

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Activity 2- Sensory fusion in support of VRT-1 research tasks – i.e. breadth of information and interactivity. (Addressing Goal 2)

- Objectives: Develop efficient models across sensory systems

- Significant Results: The main objective of this activity is to facilitate the interactivity and breadth of information provided in our virtual reality applications for seamless tele–operation of robotic agents as well as tele-presence in the virtual environment. During the last reporting period we have mainly focused on the research question regarding the fusion of sensory information to recognize hand and finger movements for recognition of human user' s intention behind structured actions with important and tangible effects into the virtual environment (Simmons, 2018). In order to address this issue, a system is developed to combine data glove information with finger movements from a motion capture system into a hierarchical model of intent-action-gesture mechanism.

- Key Outcomes: The strength of the proposed work over previous research is in the real-time and natural interactions that the virtual hands have with their environment. By being able to infer intents behind an activity before the completion of the activity, we can alleviate time-delay issues and provide for a more seamless and intuitive control mechanism for teleoperation. The proposed intent recognition model covers a wider range of intentions recognizable by traditional frameworks (Kelley, 2016), (Kelley, 2012), and (Kelley, 2010).

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Activity 3- Designing a framework in support of the VRT-2 research tasks – i.e. depth of information and immersion. (Addressing Goal 3)

- Objectives: Develop blended reality frameworks for teleoperation

- Significant Results: In order to alleviate the issues with the traditional VR systems in representing the real environment a novel augmented reality framework is developed that allows us to bring a real object captured from a

stereoscopic camera on-board the robot into the virtual environment (Tavakkoli, 2017).

- Key Outcomes: By utilizing this new mechanism, we can capture video input from the real-world and bring objects of interest into the virtual environment without the need to create 3D mesh or models.

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Activity 4- Parallelization and acceleration of computational requirements using CUDA architecture, the VRT-3 research tasks. (Addressing Goal 4)

- Objectives: Identify bottlenecks in supported computation. Develop accelerators to address the identified bottlenecks.

- Significant Results: During the last reporting period, our team has focused on identifying the computational processes suitable for acceleration. Analyzing the amount of data parallelism required in support of the computation needed for the sensory fusion tasks has revealed several potential areas for which accelerators based on massively data parallel heterogeneous architecture offered by CUDA could be designed.

- Key Outcomes: During this reporting period we have accelerated the computations in support of generating surface normal maps for the development of 3D terrain data from RGB images. In order to maintain the source code portability and maintainability requirements, several contributions to the HEMI (Harris, 2017) have been proposed (Wilson, 2017b and Wilson, 2016). This approach maintains a single implementation of each accelerated algorithm while still providing the flexibility of executing on the CPU or GPU. We showed performance increases of more than 2 order of magnitude with the acceleration of modules in our global visual sensory systems (Porr, 2018a) and (Porr, 2018b).

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Discussion:
During the last reporting period, the first and second iterations of the Virtual Reality environment developed during the first two years of the project has been significantly improved. To improve this environment and to enhance its efficiency, refined models of interaction are develop, while several sensory systems and robotics agents have been integrated into this environment. To further improve the proposed framework higher order models of intent and activities as well as intent recognition are under investigation to add to the processes within the framework.

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Bibliography
Please see the attachment for cited work.

Training Opportunities: Students participating in this project have attended two conferences for Professional development:

- International Symposium on Visual Computing, December 2018.
- IEEE 3D User Interfaces Symposium, March 2017.

The PI also hosted one student through the Army Educational Outreach Program (AEOP) Research and Educational Apprenticeship Program (REAP), one student through High School Apprenticeship Program (HSAP), and one undergradaute student through Undergradaute Research Apprenticeship Program (URAP) in the summer of 2018.

Results Dissemination: The results of the project have been published as conference and poster presentations in the following scientific venues:

- International Symposium on Visual Computing, December 2018.
- IEEE International Conference on Virtual Reality and IEEE 3D User Interfaces Symposium, March 2017.

In addition, the PI and his research group, in conjunction with the STEM division at the University of Houston-Victoria, held a one-day Mathematics and Robotics Awareness event in May 2018. There were 250 high school students in attendance. This event is the keystone of bringing high school students to the university to learn about Mathematics and Robotics at UH-Victoria and to encourage them to pursue degrees in STEM, in particular in Computer Science, Mathematics, and Robotics.

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Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Alireza Tavakkoli
Person Months Worked: 12.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: David McFadden
Person Months Worked: 12.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Sean Simmons
Person Months Worked: 12.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Loveth Ohenhen
Person Months Worked: 12.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Undergraduate Student
Participant: Jake Regenbrecht
Person Months Worked: 3.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

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Participant Type: Undergraduate Student
Participant: Isaac Elenbass
Person Months Worked: 9.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Undergraduate Student
Participant: James Easton
Person Months Worked: 2.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: High School Student
Participant: Marco Di Leo
Person Months Worked: 2.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Undergraduate Student
Participant: William Porr
Person Months Worked: 2.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: High School Student
Participant: Toby Orekoya
Person Months Worked: 2.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

CONFERENCE PAPERS:

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Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: IEEE Virtual Reality Conference
Date Received: 12-Jul-2016 Conference Date: 19-Mar-2016 Date Published:
Conference Location: Greenville, SC
Paper Title: Hand Motion Calibration and Retargeting for Intuitive Object Manipulation in Immersive Virtual Environments
Authors: Brandon Wilson, Matthew Bounds, Alireza Tavakkoli
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: IEEE International Symposium on Robot and Human Interactive Communication
Date Received: 28-Aug-2016 Conference Date: 27-Aug-2016 Date Published: 01-Sep-2016
Conference Location: New York, NY
Paper Title: An Integrated Architecture for Telerobotics Aided by Immersive Virtual Reality
Authors: Matthew Bounds, Brandon Wilson, Alireza Tavakkoli, Donald Loffredo
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: IEEE International Symposium on Robot and Human Interactive Communication
Date Received: 12-Jul-2016 Conference Date: 27-Aug-2016 Date Published: 01-Sep-2016
Conference Location: New York, NY
Paper Title: An Intuitive Human Interface for Remote Operation of Robotic Agents in Immersive Virtual Reality Environments
Authors: Jace Regenbrecht, Alireza Tavakkoli, Donald Loffredo
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 2-Awaiting Publicat
Conference Name: Software Engineering and Architectures for Realtime Interactive Systems Workshop
Date Received: 28-Aug-2016 Conference Date: 19-Mar-2016 Date Published: 23-Mar-2016
Conference Location: Greenville, SC
Paper Title: A Full-Body Motion Calibration and Retargeting for Intuitive Object Manipulation in Immersive Virtual Environments
Authors: Brandon Wilson, Matthew Bounds, Alireza Tavakkoli
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 3-Accepted
Conference Name: International Symposium on Visual Computing
Date Received: 29-Oct-2016 Conference Date: 12-Dec-2016 Date Published: 12-Dec-2016
Conference Location: Las Vegas, NV
Paper Title: An Integrated Cyber-Physical Immersive Virtual Reality Framework with Applications to Telerobotics
Authors: Metthew Bounds, Brandon Wilson, Alireza Tavakkoli, Donald Loffredo
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 3-Accepted
Conference Name: International Symposium on Visual Computing
Date Received: 29-Oct-2016 Conference Date: 12-Dec-2016 Date Published: 12-Dec-2016
Conference Location: Las Vegas, NV
Paper Title: Automatic Environment Map Construction for Mixed Reality Robotic Applications
Authors: David McFadden, Brandon Wilson, Alireza Tavakkoli, Donald Loffredo
Acknowledged Federal Support: **Y**

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Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: IEEE 3DUI
Date Received: 22-Mar-2017 Conference Date: 18-Mar-2017 Date Published: 22-Mar-2017
Conference Location: Los Angeles, CA
Paper Title: A Robust and Intuitive 3D Interface for Teleoperation of Autonomous Robotic Agents through Immersive Virtual Reality Environments
Authors: Jace Regenbrecht, Alireza Tavakkoli, Donald Loffredo
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: International Symposium on Visual Computing
Date Received: 16-Nov-2018 Conference Date: 19-Nov-2018 Date Published: 10-Nov-2018
Conference Location: Las Vegas, NV
Paper Title: GPU Accelerated Non-Parametric Background Subtraction
Authors: William Porr,James Easton,Alireza Tavakkoli, Donald Loffredo, and Sean Simmons
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: International Symposium on Visual Computing
Date Received: 16-Nov-2018 Conference Date: 19-Nov-2018 Date Published: 10-Nov-2018
Conference Location: Las Vegas, NV
Paper Title: Accurate and Efficient Non-Parametric Background Detection for Video Surveillance
Authors: William Porr, James Easton, Alireza Tavakkoli, Donald Loffredo, and Sean Simmons
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: International Symposium on Visual Computing
Date Received: 16-Nov-2018 Conference Date: 19-Nov-2018 Date Published: 10-Nov-2018
Conference Location: Las Vegas, NV
Paper Title: Sensory Fusion and Intent Recognition for Accurate Gesture Recognition in Virtual Environments
Authors: Sean Simmons, Kevin Clark, Alireza Tavakkoli, and Donald Loffredo
Acknowledged Federal Support: **Y**

DISSERTATIONS:

Publication Type: Thesis or Dissertation
Institution: University of Houston-Victoria
Date Received: 28-Aug-2016 Completion Date: 8/6/16 5:46AM
Title: A Framework for Immersive Virtual Telepresence with Application to Telerobotics
Authors: Matthew Bounds
Acknowledged Federal Support: **Y**

Publication Type: Thesis or Dissertation
Institution: University of Houston-Victoria
Date Received: 27-Aug-2018 Completion Date: 8/10/18 9:30PM
Title: Influence of Error on Trust in Human-Robot Team Interaction
Authors: Loveth Ohenhen
Acknowledged Federal Support: **Y**

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