(*L-3 / Space Grant Stipend*)
Object Recognition in Point Cloud Data using AI Aspects

Brian Fehrman

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Executive Summary

Computer vision has long been performed in a flat, two-dimensional world. The real world, however, is not two-dimensional. Projecting the world onto a plane has inherent consequences such as ambiguities when trying to recognize objects within a scene. For instance, a picture of an object could be mistaken for the real life item [1]. To overcome the inaccuracies of flattening the world there has been a large effort towards algorithms using three and four dimensional point cloud data. Some of the fuel for the interest has been the recent availability of low cost natural interface devices such as the Microsoft Kinect sensor which can scan the environment and provide a cloud point representation of what it sees. These devices can easily be fitted to robots and ultimately used for tasks such as object recognition within a scene. Here the goal is to improve upon existing object recognition algorithms by investigating artificial intelligence techniques such as evolving a recurrent neural network that can be used to identify items that are encountered.

Current State

One of the most prevalent initiatives in point cloud data algorithms is the Point Cloud Library project. The Point Cloud Library, or *PCL*, is a large scale, stand alone, and open source project for both 2D and 3D point cloud processing. The PCL contains many advanced image processing functions such as 3D point cloud stitching and object recognition. Devices using the OpenNI 3D (e.g., Microsoft Kinect) interface can send their data to a program for processing via the PCL [2].

Aldoma et al researched fast 3D feature based object recognition and pose estimation. Their aim was to take a set of CAD models that represented how we perceive an item in the world and then accurately identify each one of those

objects in a real world scene using a depth sensor. The algorithm was an extension of the Viewpoint Feature Histogram (VFH) and is more geared towards clustered environments and, as such, is dubbed the Clustered Viewpoint Feature Histogram ($CVFH$). They found that with using a Kinect sensor on a set of 44 objects that their algorithm was better able to recognize objects in the presence of partial occlusion and noise than the original VFH routine [3]

More recently, in collaboration with the PCL project, Aldoma and others have even further extended the CVFH algorithm such that they can repeatably place a reference frame on 3D objects in a scene. This reference frame is matched to a model reference frame in order to more easily determine an item's pose and to identify the item with greater certainty. They found that a substantial improvement was made over the CVFH method alone in terms of accuracy and computational performance. They plan to add CUDA support for future iterations of their algorithms [4].

Specific Goals

The OUR-CVFH algorithm previously described is essentially constrained to a static set of data on which it was trained. This would limit a robot in terms of its ability to adapt and learn in environments where information is encountered that has not previously been seen. The goal here is to investigate the use of Recurrent Neural Networks to identify objects within a scene and to also update their knowledge by providing some sort of a reward or fitness function to sway the decisions to be more accurate. The outcome would be improved robustness over the existing state of the art in terms of object detection within a cluttered, noisy, unpredictable environment.

Research Activities

The first and foremost activity will be an in depth literature review of the past and present research on point cloud data. This will include not only object recognition algorithms, but also more low level routines such as edge detection, segmentation, and other topics that could be beneficial. Research will be conducted on recurrent neural networks and methods for training them such as evolutionary techniques. Since intelligence and biological concepts underlie all of this it will also be worth while to take a closer look at how humans recognize objects and perceive their environment as this sort of view can often give great insight. The algorithms developed will be tested using simulations and a natural interface sensor and performance will be compared to existing approaches.

Metrics

The following lists the specific metrics to define the success of the research:

- Develop recurrent neural network for object recognition in point cloud data
- Show that the neural network will can learn based upon new information
- See that the newly developed solution performs better in terms of accuracy and speed than the current algorithms

Timeline

- Literature review

  Present - February 2013

- Combine information from research into an algorithm to robustly detect objects in a scene and learn new information

  February 2013 - June 2013

- Code, debug, and test the algorithm

  June 2013 - November 2013

- Revise algorithm and test against other solutions

  November 2013 - March 2014

- Finalize research

  March 2014 - May 2014

SDSGC and this Research

Awarding a Space Grant stipend for this research will directly address, among other goals, the SDSGC Objective B.2.2 and Strategy B.2.2.3 by supporting multi-disciplinary graduate research that is aligned with NASA's mission since this technology could be very valuable to autonomous robots in space. This stipend will assist in the research by allowing me to better focus on the work at hand without external financial concerns. Good results from this could jump start my career into the STEM disciplines which is something that I have always sought after. My love of what I do makes me a natural fit for the field which could lead to great accomplishments such as owning a successful business that can continue to provide funds for exciting and useful research.

References

[1] Radu Rusu and Michaul Dixon, editors. *Point Cloud Library on CUDA*. GPU Technology Conference, 2012.

[2] PCL. Pcl introduction. www.pointclouds.org. Online: Accessed 10-1-2012.

[3] A. Aldoma, M. Vincze, N. Blodow, D. Gossow, S. Gedikli, R.B. Rusu, and G. Bradski, editors. *CAD-model recognition and 6DOF pose estimation using 3D cues*. IEEE Computer Vision Workshop, 2011.

[4] Aitor Aldoma, Federico Tombari, Radu Bogdan Rusu, and Markus Vincze. Our-cvfh - orientied, unique, repeatable clustered viewpoint feature histogram for object recognition and 6dof pose estimation. *Lecture Notes in Computer Science*, 7476:113–122, 2012.

Brian Fehrman

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Work History:

- CSC Teaching Assistant, SDSMT, Rapid City, South Dakota (2012 – present)
- Research Engineer, SDSMT Advanced Dynamics Lab, Rapid City, South Dakota (2007 – 2012)
- Retail Associate, Sam's Club, Rapid City, South Dakota, (2002 – 2007)

Education:

- M.S. CSR South Dakota School of Mines and Technology, Rapid City, SD 2014
- M.S. M.E. South Dakota School of Mines and Technology, Rapid City, SD 2012
- B.Sc. CSC South Dakota School of Mines and Technology, Rapid City, SD 2010
- Minor Math South Dakota School of Mines and Technology, Rapid City, SD 2010

Background:

- **Time Reversal Acoustics**: Successfully performed time reversal signal processing to focus of acoustic stress wave energy in rods of varying media.
- **Extensive Programming**: Possesses programming knowledge that is both broad and deep which allows for using the right software tool for the job and converting code between different languages such as Matlab, C++, C#, LabVIEW, and others.
- **FGPA Data Acquisition**: Has written many programs that efficiently harness the speed and reliability of FPGA data acquisition cards.
- **Circuit Boards**: Personally designed and milled circuit boards with many hours logged on the CNC milling machine which cuts down costs of outsourcing fabrication.
- **Custom Animation**: Created a variety of computer animation programs to better help convey concepts and ideas about different lab projects.
- **Mobile Development**: Developed simple games for the android platform.

Recognition / Honors:

- 3rd Place, South Dakota School of Mines Student Research Competition, May 2010, topic of *Self-Healing and Acoustic Time Reversal Focusing*
- Recipient of a 2011 NASA SD Space Grant Award in the highest amount.

Professional:

- Member of Triangle Fraternity 2008-Present
- Member of Association for Computing Machinery 2008-present
- Member of American Institute of Aeronautics and Astronautics 2009-present
- Member of SPIE 2009-Present
- Member of IEEE 2010-Present

Selected Publications:

- **First Author –** *Targeted Delivery of Acoustic Energy for Self-Healing.* Submitted for review to the Journal of Intelligent material Systems and Structures. August 2012.
- **First Author –** *Iterative Time Reversal in Dispersive and Non-Dispersive Media.* Accepted for publication by AIAA and is to be presented at the 2012 AIAA 53rd Structures, Structural Dynamics, and Materials Conference.
- **First Author** - *Time Reversed Focusing in Finite-Length Rods with Defects.* Accepted for publication by AIAA and was presented at the 2011 AIAA 52nd Structures, Structural Dynamics, and Materials Conference.
- **Co-Author** - *Experiments on the focusing and use of acoustic energy to enhance the rate of polymer healing*. Accepted for publication by SPIE and was presented at SPIE 2011 Smart Structures Conference.
- **First Author** - *Using Focused Acoustic Excitation to Accelerate Crack Healing.* Published by AIAA and was presented at the 2010 AIAA 51st Structures, Structural Dynamics, and Materials Conference.
- **Co-Author –** *Electrostatic control with discrete area variation for beam steering and focusing using membrane mirrors.* Accepted for publication by SPIE and was presented at SPIE 2010 Smart Structures Conference.

Welcome Brian!

Course Listing

If there is a letter following the course number, it indicates the university where the course was taken.
B = Black Hills State University, D = Dakota State University, M = SD School of Mines & Technology,
N = Northern State University, S = South Dakota State University, U = the University of South Dakota.

Name Fehrman, Brian C.
Address 28 Colbalt Dr
Rapid City, SD 57701

Course/Section and Title	Grade	Credits	Repeat	Term
CSC-317 M001 Computer Organiz & Architectur	B	4.00		2010SP
CSC-317L M051 Computer Organization/Arch Lab	LR	0.00		2010SP
CSC-467 M001 Senior Design II	B	2.00		2010SP
MATH-315 M001 Linear Algebra	B	3.00		2010SP
MATH-321 M002 Differential Equations	B	4.00		2010SP
MATH-381 M002 Intro to Prob and Stats	B	3.00		2010SP
CSC-421 M001 Graphical User Interfaces	A	3.00		2009FA
CSC-465 M001 Senior Design I	A	2.00		2009FA
CSC-492 M082 TP: SOFTWARE ENGINEERING	A	3.00		2009FA
MATH-423 M001 Advanced Calculus I	C	4.00		2009FA
PHYS-213 M001 University Physics II	B	3.00		2009FA
PHYS-213L M052 University Physics II Lab	A	1.00		2009FA
HUM-375 M001 Computers in Society	A	3.00		2009SU
CSC-410 M001 Parallel Computing	A	3.00		2009SP
CSC-447 M001 Artificial Intelligence	B	3.00		2009SP
CSC-461 M001 Programming Languages	A	4.00		2009SP
ENGL-289 M007 Technical Communications II	A	3.00		2009SP
PE-100 M001 Activity Courses-Weight Train	A	1.00		2009SP
CHEM-114 M001 General Chemistry II	B	3.00		2008FA
CSC-372 M001 Analysis of Algorithms	A	3.00		2008FA
CSC-484 M001 Database Management Systems	B	3.00		2008FA
ENGL-279 M003 Technical Communications I	A	3.00		2008FA
PHYS-211 M001 University Physics I	A	3.00		2008FA
PHYS-211A M012 University Phys I Recitation	LR	0.00		2008FA
CENG-244 M001 Intro to Digital Systems	A	4.00		2008SP
CENG-244L M052 Intro to Digital Systems Lab	LR	0.00		2008SP
CSC-433 M001 Computer Graphics	C	3.00		2008SP
CSC-456 M001 Operating Systems	B	4.00		2008SP
CSC-456L M051 Operating Systems Lab	LR	0.00		2008SP
SPAN-102 M021 Introductory Spanish II	A	4.00		2008SP
PE-118 M001 Beginning Swimming	A	1.00		2007FA
BIOL-121 M001 Basic Anatomy	B	3.00		2007FA
MATH-225 M004 Calculus III	B	4.00		2007FA
SOC-100 M003 Introduction to Sociology	B	3.00		2007FA
SPAN-101 M021 Introductory Spanish I	A	4.00		2007FA
CSC-300 M001 Data Structures	C	4.00		2007SP
CSC-314 M001 Assembly Language	D	4.00		2007SP
CSC-314L M051 Assembly Language Lab	LR	0.00		2007SP
MATH-225 M003 Calculus III	W	0.00		2007SP

PHIL-200 M001 Introduction to Logic	A	3.00		2007SP
CHEM-112 M001 General Chemistry I	D	3.00		2006FA
CHEM-112L M053 General Chemistry I Lab	B	1.00		2006FA
CSC-250 M001 Computer Science II	B	4.00		2006FA
CSC-251 M001 Finite Structures	D	4.00		2006FA
MATH-125 M002 Calculus II	C	4.00		2006FA
CSC-150 M004 Computer Science I	B	3.00		2006SP
CSC-150L M052 Computer Science I Lab	LR	0.00		2006SP
ENGL-101 M004 Composition I	B	3.00		2006SP
MATH-123 M004 Calculus I	C	4.00		2006SP
PSYC-101 M002 General Psychology	B	3.00		2006SP

Total Earned Credits	134.00
Total Grade Points	409.00
Cumulative GPA	3.052

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Name Fehrman, Brian C.
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Course/Section and Title	Grade	Credits	Repeat	Term
CSC-515 M001 Introduction to Robotics				2012FA
CSC-515L M051 Lab: Introduction to Robotics				2012FA
CSC-549 M001 Pattern Recognition				2012FA
CSC-790 M081 Seminar				2012FA
EE-592 M081 TP: COMPUTER VISION				2012FA
ME-898D M084 Dissertation	NP	0.00		2012SU
ME-691 M081 Independent Study	A	3.00		2012SP
ME-691 M083 IND: ROBOTICS	A	3.00		2012SP
ME-898D M081 Dissertation	NP	0.00		2012SP
ME-625 M001 Smart Structures	A	3.00		2011FA
ME-898D M084 Dissertation	NP	0.00		2011FA
PHYS-521 M001 Electromagnetism	A	4.00		2011FA
ME-898D M084 Dissertation	NP	0.00		2011SU
ME-773 M001 Applied Engineering Anal II	A	3.00		2011SP
ME-798 M086 Master's Thesis	NP	0.00		2011SP
PHYS-551 M001 Classical Mechanics	B	4.00		2011SP
EE-505 M001 Survey of Circuits & Systems	A	3.00		2010FA
EE-505L M051 Survey of Circuits/Systems Lab	LR	0.00		2010FA
ME-673 M001 Applied Engineering Analysis I	A	3.00		2010FA
ME-798 M085 Master's Thesis	NP	0.00		2010FA
ME-798 M081 Master's Thesis	NP	0.00		2010SU

Total Earned Credits 26.00
Total Grade Points 100.00
Cumulative GPA 3.846