Institution: University of Lincoln		
Unit of Assessment: 11 – Computer Science and Informatics		
Title of case study: Geoteric – Deep Learning for Hydrocarbon Exploration		
Period when the underpinning research was undertaken: 2004 - 2018		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
HUNTER Andrew CHUDZIK Piotr	DVC Research and Innovation Research Assistant	1 Jan 04 to date 18 Jan 16 – 31 Mar 19
Period when the claimed impact occurred: 2019 - 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Working with UK-based SME "Geoteric" the University of Lincoln adapted its "Deep Learning" technology to detect geological faults in seismic survey data for hydrocarbon exploration allowing rapid detection, better understanding of drilling risk, fewer unsuccessful wells, and asset life extension. Geoteric acquired the IP from the University, leading to the creation of new jobs, staff development within Geoteric and integration of the technology into a new sector-leading 'software as a service' product "*AI Faults*". AI Faults has enabled Geoteric to dramatically accelerate structural reconnaissance of fault datasets, with more thorough maps than previously possible, and demonstrating the ability to avoid high costs of wasted drilling. In the first twelve months of service Geoteric undertook 10 commercial projects using AI Faults with operational benefits for international oil companies.

2. Underpinning research (indicative maximum 500 words)

The computer vision group at the University of Lincoln has a long track-record in applying a variety of methods, including neural networks, to the segmentation of images. In our 2004 paper **[3.1]** we showcased our newly developed methods to make highly accurate measurements of blood vessels in 2D retinal images. In 2009 we developed this technology further, building active contour models for segmentation of entire blood vessel networks **[3.2].** In 2015 in the REVAMMAD project we began investigating the use of Deep Learning (DL) technology for these segmentation tasks, publishing results in 2017-2019. Apart from segmenting vessels, we also focused on segmenting clinically relevant lesions: microaneurysms and exudates. We were the first research team worldwide to explore similarity learning in context of retinal imaging in **[3.3]**. This work also presented one of our custom designed architectures for this domain. In **[3.4]** we described a novel method for microaneurysm segmentation using fully convolutional neural networks. We improved this method through use of transfer learning and regularization embedded into the architecture **[3.5].** Next, we proposed a fully automated method for exudates segmentation which are crucial for diabetic retinopathy screening **[3.6].** Finally, we combined a DL model with a visual codebook approach to segment retinal vessel trees **[3.7].**

In 2017, we undertook a funded project with Geoteric (further company detail in section 4), to look at adaptation of our DL technology to the detection of seismic faults. We based the developed software on several key aspects of our underlying technology, specifically:

a. Patch-based approach described in **[3.3].**
b. Fine-tuning techniques (including novel Interleaving Freezing method) proposed in **[3.4].**
c. A novel fully convolutional architecture combined with batch normalization layers, image pre-processing algorithm, and DICE loss function proposed in **[3.5].**

d. Transfer learning approaches for limited datasets summarized in **[3.6].**
e. Combination of a deep learning model with a visual codebook, multi-scale patch method, and target reduction technique using Totally Random Trees Embedding presented in **[3.7].**

3. References to the research (indicative maximum of six references)

3.1 Measurement of retinal vessel widths from fundus images based on 2-D modeling (2004)
J Lowell, A Hunter, D Steel, A Basu, R Ryder, RL Kennedy
IEEE transactions on medical imaging 23 (10), 1196-1204
http://dx.doi.org/10.1109/TMI.2004.830524
http://eprints.lincoln.ac.uk/1216/1/Lowell2004TMIMeasurementOfRetinalVesselWidthsFromFundusImagesBasedOn2DModeling.pdf

3.2 An active contour model for segmenting and measuring retinal vessels (2009)
B Al-Diri, A Hunter, D Steel
IEEE Transactions on Medical imaging 28 (9), 1488-1497
http://dx.doi.org/10.1109/TMI.2009.2017941
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4804753

3.3 Learning deep similarity in fundus photography (2017)
P Chudzik, B Al-Diri, F Caliva, G Ometto, A Hunter
Medical Imaging 2017: Image Processing 10133, 101332A
http://dx.doi.org/10.1117/12.2254286

3.4 Microaneurysm detection using deep learning and interleaved freezing (2018)
P Chudzik, S Majumdar, F Caliva, B Al-Diri, A Hunter
Medical Imaging 2018: Image Processing 10574, 105741I
http://dx.doi.org/10.1117/12.2293520
http://eprints.lincoln.ac.uk/31548/1/inter_freezing.pdf

3.5 Microaneurysm detection using fully convolutional neural networks (2018)
P Chudzik, S Majumdar, F Calivá, B Al-Diri, A Hunter
Computer methods and programs in biomedicine 158, 185-192
https://doi.org/10.1016/j.cmpb.2018.02.016
http://eprints.lincoln.ac.uk/31182/7/31182%20manuscript_chudzik.pdf

3.6 Exudate segmentation using fully convolutional neural networks and inception modules (2018)
P Chudzik, S Majumdar, F Caliva, B Al-Diri, A Hunter
Medical Imaging 2018: Image Processing 10574, 1057430
http://dx.doi.org/10.1016/j.cmpb.2018.02.016
http://eprints.lincoln.ac.uk/31549/1/exudates.pdf

3.7 DISCERN: Generative Framework for Vessel Segmentation using Convolutional Neural Network and Visual Codebook (2018)
P Chudzik, B Al-Diri, F Caliva et al
40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) 5934-5937. ISSN 1557-170X
https://doi.org/10.1109/EMBC.2018.8513604
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8513604

4. Details of the impact (indicative maximum 750 words)

In 2017 we were approached by Foster Findlay Associates Limited (trading as “Geoteric”), a UK SME providing innovative software solutions to the oil industry, to explore the potential for UoL Deep Learning technology to enhance fault detection in seismic surveys. In early stage exploration, large areas are surveyed to understand the structural geology of the subsurface. Highly skilled geologists use semi-automated interpretation software tools to depict geological features including faults, which are critical to many aspects of petroleum systems (e.g. trap formation, migration pathways and sealing). It typically takes months to complete an analysis, against restrictive timescales and with the associated cost of subsequent drilling likely in excess of £20m, with significant risk of failure.

Geoteric identified the potential to adapt UoL's research into Deep Learning technology and linear structure segmentation to automate detection of geological faults, and commissioned UoL to develop a prototype DL-based solution.

Following high performance in preliminary testing, Geoteric licensed the IP in 2018 **[5.1]** and created a new Deep Learning team consisting of one full-time DL specialist, a student intern and providing DL training for three other members of staff. Geoteric has acknowledged that working with the University was critical to the rapid development of Deep Learning software and their business model:

> *"Working with the IP generated by University of Lincoln provided a framework to expedite research and development, reducing the time to market."* **[5.2]**.

Geoteric further developed the software, using the critical knowledge introduced by Chudzik, resulting in a new system: "*AI Faults*". This was tested against a set of real-world case studies **[5.3]**, including an existing manual fault depiction on the Canning TQ3D survey covering 4400 Km2 of an underexplored part of the Beagle Sub-basin, NW Shelf Australia. The original publicly available and comprehensive manual survey took around six months to complete. By contrast, "AI Faults" compiled an equivalent dataset within days, closely aligned to the manual analysis and (crucially) in much greater detail. Such detail would be impossible to manually interpret within traditional project timescales **[5.4]**. Another test retrospectively analyzed data from a previously drilled location (Tern-Eider Ridge, **[5.5]**), with "AI Faults" detecting a fault running through a collapsed well that the traditional methods had missed, resulting in £1m in wasted drilling costs. DL-enhanced software therefore enables Geoteric to provide dramatically accelerated structural reconnaissance of big datasets, and more thorough and detailed maps of potential drilling areas than was previously possible:

> *"The timescale for oil exploration cycles are extremely long and demand a multi-million-pound investment by drilling companies to locate, assess, select and ultimately drill to find oil. … The new software is a gamechanger. It not only accelerates this process and saves companies considerable money but reduces risk.* **[5.2].**

With proven performance, in July 2019 Geoteric introduced a new business model, providing a software service model for exploration companies to submit data for analysis, providing quicker and more accurate mapping of faults and risks. As Geoteric state:

> *"With AI Faults in place, we can prove the cost savings to customers and grow not only our business but a more efficient exploration process".* **[5.2]**

The introduction of AI Faults has been transformational for Geoteric. In the first twelve months of the service, Geoteric undertook 10 commercial projects on datasets from a range of global basins, an extremely rapid market penetration for a new technology. Geoteric has also now sold its first license of a new SaaS product, incorporating the AI Fault technology.

> *"AI Faults has enabled us to extend our global footprint and increasing our technological edge in a highly competitive international market. Within our business we've kick-started our internal expertise in AI technology and built a dedicated in-house team to serve this growing market. Not only can we now deliver huge savings to our customers, but by increasing asset life we are able to help reduce damage to the environment which would otherwise have been unavoidable. AI Faults is now a critical part of our product line, and*

we expect Deep Learning to be an essential part of our business in the future". **[5.2]**.

Despite the length of the oil exploration cycle, these proven technical advances have already translated beyond benefits to Geoteric and into customers' businesses. Wellesley Petroleum, the Norwegian oil exploration specialists report that *"Geoteric's AI-Fault interpretation has an immediate impact on our subsurface understanding, enabling an improvement to our well planning process."* **[5.6].** Aker BP's Lead Geophysicist on the North Sea Valhall field stated: "*This has improved the rigour of our work so that our decisions are based on a better understanding of where faults may introduce drilling risks.*" **[5.7].**

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1 IP transfer agreement between Geoteric and UoL

5.2 Testimonial from Geoteric R&D lead.

5.3 Geoteric case studies (https://www.geoteric.com/case-studies).

5.4 Geoteric case study: Structural interpretation – Canning https://www.geoteric.com/canningbasin-case-study .

5.5 Geoteric case study: Drilling risk avoidance - Tern Eider Ridge https://www.geoteric.com/tern-case-study

5.6 Geoteric "AI Integration" – summary of technology including supporting statements from end-users on effectiveness (https://www.geoteric.com/ai-integration)

5.7 Geoteric case study: Enhancing operational efficiency - Aker BP https://www.geoteric.com/akerbp-case-study