Project Title: Using Perceptual Grouping and Segmentation to Improve Aviation Maintenance

CS50100 Computing for Science and Engineering

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Team Members: Javier Belmonte, Xin Ding, Maria Kon[*], Laith Sakka, William Weldon.

[*] Team leader.

1. Problem Statement

We are solving two interrelated problems.

The Rivet Analyzer Problem: our project will offer a solution to the problem of providing an autonomous system that can scan rows of rivets on aircraft, detect damage over a row of rivets, and map the rivet positions in relation to the other rivets.

The Grouping Problem: our project will also go towards solving the problem of creating and implementing a biologically-based circuit in an existing neural network of the visual system such that the network can group elements of a visual scene, e.g., rivets in a photo of an aircraft wing, into objects, e.g., undamaged rivets, and patterns, e.g., rows of rivets.

2. Why is the problem important?

Regarding the *Rivet Analyzer Problem:* Rivets are the main fasteners used on aluminum aircraft, and during an airframe inspection these rivets must be assessed. Any passenger jet contains tens of thousands of identical rivets. Creating a vehicle to follow a rivet row and gather visual data on the rivets, and track the rivet positions, would allow aircraft manufacturers and operators to accurately map their positions. Autonomously mapping rivets would allow subsequent maintenance visits to compare rivet conditions and show how the fasteners wear over time. This information would also allow for airframe digital twins to be created. Many aircraft are made individually and the location of the rivets varies slightly from aircraft to aircraft and this makes creating an airframe digital twin challenging.

Regarding the *Grouping Problem*: Much experimental work has been done in psychology on perceptual grouping, i.e., how humans determine which elements in a visual scene form groups such as objects and patterns. However, there is not a well-developed mechanistic account of grouping. For example, consider the computational representation of the human visual system called LAMINART. Although LAMINART has a viable collection of circuits for outputting information about boundaries and luminance, it currently lacks a well-developed, biologically-based way of segmenting and grouping this information. Note that by ‘a biologically-based way’, we mean a way that is at least consistent with the results of a wide range of psychophysical experiments.

3. Approach

To solve this problem, we will feed compressed images from a GoPro camera attached to a Lego EV3 robot into a computational model of human visual perception called LAMINART. The output of

LAMINART will be used to control the robot and resolve the aircraft maintenance problems specified above.

More specifically, we will:

1. Determine how to split up and compress video from the GoPro camera on the vehicle such that a reasonable amount of data is intact, e.g., use PCA to compress images taken at fixed time steps, that is also suitable as input into LAMINART such that it finishes processing the images in a reasonable amount of time given this task.
2. Create and code a biologically-based circuit that allows LAMINART to perform the grouping tasks necessary to analyze rivets. Additionally, we may have to optimize the LAMINART network so that it can process images with a reasonable speed.
3. Create and implement code that uses output from LAMINART at various stages to: detect the wing edge and instruct the vehicle to move appropriately, detect rivet damage via either: (Option 1) a comparison process in which either individual rivets or a row of rivets are compared with a template and their match is quantified (perhaps using some error function), or (Option 2) develop the segmentation process such that LAMINART outputs images groups non-damaged rivets and discerns damaged rivets from these groups.
4. Run trials with the robot to determine to what extent the code does or does not work and modify the code to resolve problems that arise.

4. Related work

Aviation

Currently very little work has been done in mapping rivet rows, but a good amount of research has been done in creating digital twins for aircraft. Glassgen, and Stargel (2012) outline the potential future that digital twin models have in the USAF and NASA. This publication also provides a list of many handbooks and standards that would need to be used in creating a digital twin. Tuegel (2012) presents some of the challenges to realizing an airframe digital twin (ADT). The first problem that is stated is "Establishing the initial conditions for the ADT," and this project stands to assist in establishing one part of the initial aircraft condition. This initial condition is the actual condition of the aircraft as it currently exists. This condition is difficult to determine when the aircraft leaves the factory and is nearly impossible to determine after the aircraft has been in service.

Grouping

Grossberg and colleagues, e.g., Grossberg and Mingolla (1985), provide a theory of real-time visual processing the involves two main interconnected circuits: the Boundary Contour System (BCS) and the Feature Contour System (FCS). Given an image, BCS, which creates real and illusory boundaries, and FCS, which 'fills in' luminance within bounded elements, work together to output an image with boundaries and luminance. One recent model that uses this theory is LAMINART. LAMINART is a neural network. It models bottom-up processes, e.g., activity of cells in the human retina, and incorporates top-down processes, i.e., it uses a segmentation process to model perceptual processes driven by cognition. However, although the version of LAMINART implemented by Francis, Manassi, and Herzog (2017) did introduce a means of grouping elements of an image, this circuit is relatively undeveloped. In particular, its selection signals are, effectively, two randomly located circles of a single diameter placed on the image. So, while this version of LAMINART simulated the results of some psychophysical experiments, its novel segmentation process is very limited and requires development.

5. Deliverables

The main aim is to program a vehicle that can: follow a row of rivets on an aircraft wing, not fall off the wing, detect damage over the row of rivets, and map the rivet positions in relation to the other rivets.

We will produce code in Python that: controls the Lego EV3 robot, (maybe) compresses the GoPro video into images, develops LAMINART's segmentation process such that it performs well on this task and is biologically-based.

Additionally, since we have access to a Lego EV3 and aircraft, we will attempt to make this vehicle operational at a reasonable level.

6. Computing: special needs

(a) Why do we need more computing power?

We envision that more computing power will be necessary for this project because in LAMINART each pixel is represented by a single neuron, and each neuron has a circuit with various connections and weights. Each pixel in the output of LAMINART represents the firing rate of a neuron over 50ms, such that pixel brightness corresponds proportionately to firing rate, i.e., the brighter the pixel, the faster the neuronal firing rate. So, the more pixels, the more time it takes to run LAMINART. Further, we will have a number of images to process as the vehicle travels across the wing. Thus, to allow the vehicle to be reasonably functional in real time, more computing power will be required.

(b) Type of data and how much GB we may need to deal with?

We will create compressed images from the video camera data. We plan to store some of the raw data in addition to the images, which we estimate will have a total size of XXXGB [Note: we will specify a number in the final version of the proposal].

7. References

Francis, G., Manassi, M., & Herzog, M. H. (2017). Neural dynamics of grouping and segmentation explain properties of visual crowding. *Psychological Review, 124*, 483-504.

Glaessgen, E., & Stargel, D. (2012). The Digital Twin paradigm for future NASA and U.S. Air Force vehicles. *53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference 20th AIAA/ASME/AHS Adaptive Structures Conference 14th AIAA* (pp. 1-14). Honolulu: AIAA. doi:DOI: 10.2514/6.2012-1818

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