

# Visual Navigation in Simulated Pigeons

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## Abstract

This research presents computational models to represent visual navigation mechanisms which guide pigeons (*Columba Livia*) during flight. A 3D graphics computer simulator was developed to model autonomous flight in virtual pigeons. The aim was to investigate the role of (i) visual landmarks (ii) flocking with other pigeons and (iii) image familiarity in pigeon navigation. A recursive processing algorithm enabled landmarks and other pigeons to be located, identified and counted. Image processing could form a feasible mechanism for autonomous visual navigation by identification of familiar route headings. This could be used in autonomous flying drones or flight simulators.

## Introduction and History

Pigeons (*Columba Livia*) were the first domesticated bird, around 6000 years ago. This long and important history of interaction with humans has enhanced their capability to communicate. Modern pigeons can understand hand signals, voice commands and recognise individual humans even when wearing different clothing (Brett et al. 2015). During domestication, the fastest and most reliable message carrier pigeons have been favoured for breeding which has produced faster, stronger pigeons which can fly further with enhanced homing ability. Homing is defined as the process of a pigeon navigating back to its loft after being released remotely – either independently or in flocks. Pigeons have been known to successfully navigate home to their loft from 7200 miles which is almost one third of Earth's circumference. Racing pigeons commonly fly at speeds of up to 80 miles per hour, flying for 24 hours without stopping.

**Navigation mechanism in pigeons.** Pigeon navigation mechanisms involve (1) the position of the sun in the sky relative to the hour of day, known as solar clock (2) sensation of the earth's magnetic forces, known as magnetoception (3) visual recognition of landmarks especially for the region closest to the loft. The solar clock is preferred by the pigeon, however on cloudy or rainy days it is not possible to use the sun and pigeons then switch to navigation by magnetoception. This has been proven by releasing 'time shifted' pigeons (Biro et al., 2004). Their blacked-out loft had no sunlight and artificial lighting was used to offset sunrise and sunset by 2 hours from the actual sunset. When released, 'time shifted' pigeons set off at the wrong angle, taking a long detour with increased chance of becoming lost, showing that pigeons navigate by solar clock when the sun is visible. However, on

cloudy days the 'time shifted' pigeons were unaffected, flying home in a straight line, proving that when the sun is not visible, pigeons navigate by magnetoception.

Breeders generally lose pigeons each year due to hazards including farmland shooting, colliding with high sided vehicles and power cables. Some losses are unavoidable but understanding navigation mechanisms could reduce losses in training caused by navigation issues or weather.

Pigeons are an example of expert visual navigators but it is not known how their vision is optimised for navigation or how their optical array is optimised for view matching strategies to enable orientation and navigation. Between the eyes of various aerial animals, there is enormous variation in the information provided by visual systems (Gaffin et al. 2015). Mechanisms of insect navigation have recently been investigated by computer simulation (Wystrach et al., 2015).

## Video recording during pigeon flight

Small lightweight video camera devices have been mounted onto a pigeon during flight which revealed the bird's eye view during pigeon navigation (Fig. 1). Results from analysis of these videos and real-time GPS tracking data during pigeon flights show that pigeons use visual navigation to follow roads, rivers, or coastlines which lead towards their loft during flights within familiar territory or within the last leg of a longer journey (Biro et al., 2004). These findings suggest that navigation within one mile of the loft is led by visual navigation of recognised landmarks. The outline of landmarks must be visible for pigeons to recognise them correctly (Gibson et al., 2015). This suggests that navigation by solar clock and magnetoception may not be accurate enough for locating the exact loft, but guides to within the correct mile. This would explain why pigeons become lost when released without first seeing and becoming familiar with the loft's surroundings, which is a core part of training for homing pigeons. Within visual navigation (i) landmarks, (ii) flocking and (iii) familiar scenes play a part in guiding pigeons. This research aims to identify their roles in simulated navigation.



Fig. 1. Video device mounted on a pigeon during flight to monitor visual navigation [National Geographic, 2011].

## Methods - Simulated Pigeon Visual Navigation

Virtual Reality habitats were generated using the GLUT framework to represent environments encountered by pigeons in their natural habitat (Fig. 2). For pigeons this consisted of a random assortment of plants and trees on hilly ground with scattered areas of water. Plants and tree objects were created using random configurations based on geometric patterns. The size of trees in the virtual environment was based on the scale of objects as perceived by the pigeons in their natural habitat at flight levels between 0-100m. Plants and trees were rendered as 3D objects. A flock of 100 pigeons was simulated, each navigating independently.

**Pigeon's eye view.** At each iteration of the simulator, a bird's eye view of each virtual pigeon in the sky was generated and stored as an image using perspective projection view from the position (latitude, longitude and altitude) within virtual world coordinates and, direction (elevation and azimuth) in degrees. The generated image proportions aim to match characteristics of pigeon eyes in terms of the degrees of panoramic view from the horizon. Various combinations of colour and resolution were investigated to represent pigeon's eye characteristics and identify the effect on ability to navigate. The pigeon's eye view images were used for (1) image processing to identify landmark features within the image, and (2) a neural network to assess familiarity of images.

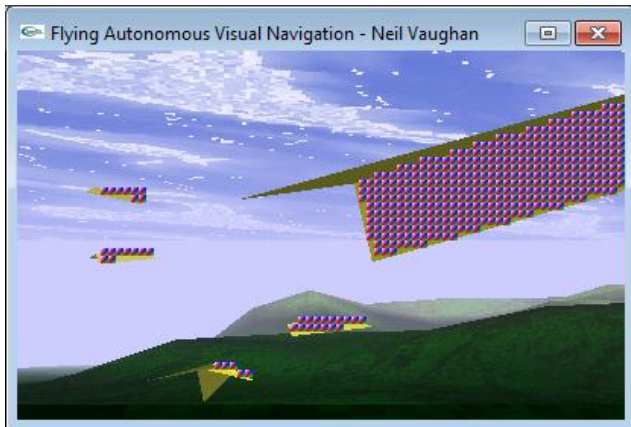


Fig. 2. Virtual Simulation of autonomous pigeon during flight.

**Image processing: landmark recognition.** Real-time Image processing algorithms were developed to process the pigeon's eye view images to identify (i) known landmarks and (ii) other pigeons to guide flocking behaviour. Recursive image processing was used to locate centroid of each object cluster (Fig. 3). A matrix represents all pixels within view. For pixels within the landmark RGB threshold, a recursive function tests the pixel values of four surrounding pixels (non-diagonal).

**Neural Network Training.** A neural network was used to assess the familiarity of images from the pigeon's eye view. The ANN was trained with stored images taken at regular intervals along a known training route through the habitat, from a familiar release site back to the loft (Wystrach et al. 2015). Distance between stored training images represents the pigeon's memory capability. The neural network required the familiar route to be clearly distinguishable from others.

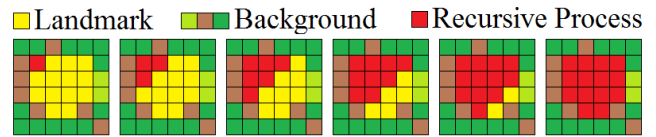


Fig. 3. Clustering recursion algorithm to identify landmarks.

## Results and Performance Analysis of Recursion

The recursive image progressing algorithm from a pigeon's view allowed all pixels within landmarks to be identified. Size and centre of each cluster was calculated from sum of pixels. This enabled identification of the number, size and location of landmarks. This could enable navigation based on the location of known landmarks to recover accurate route headings from visual perception of landmark locations. The pigeons are required to learn a map of the landmark layout in relation to the loft. Learning the loft location relative to landmarks is an essential part of the training process. The number of other pigeons was identified by image processing, enabling flocking behaviour by responding to flight paths of other pigeons.

## Conclusion

In 2016 there is increasing investment in autonomous navigation research. Beneficiaries include: driverless cars, flying delivery drones, autonomous robotics, game engines, auto-pilots and augmented smartphones.

This research used virtual models of autonomous agents within virtual environments. Image processing was used to develop visual navigation based on optical performance of pigeons. VR can provide a platform to develop and test algorithms for visual perception and navigation responding to sensory information in real-time.

The developed visual navigation algorithms from the simulator model could be transferred onto a drone with a microcontroller and camera to detect landmarks and other drones using image processing. This could enable a drone to use landmarks and scene familiarity for visual navigation and to flock or avoid collisions with other drones.

Recent research generated preliminary results validating feasibility of image processing for autonomous visual navigation (Vaughan, 2015). Familiarity of images could enable autonomous agents to choose the optimum orientation and navigation towards a trained location.

## References

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