Paper: Motion Camouflage Review
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Abstract:

This paper seeks to present and comment upon the ideas and implementations of motion camouflage research. The primary paper reviewed here is the explanation of an experiment (masquerading as a computer game) done on humans in order to establish whether human beings are deceived by motion camouflage. Section 1 will introduce the concepts of camouflage and motion camouflage in particular. Section 2 will explain, in detail, the experiment and its outcome. Section 3 will describe the motion camouflage simulation program developed by this team and used in the computer game. Section 4 will describe mathematical refinements that have been done in order to enable further research in this area. The fifth and final section will be my commentary on additional areas of research that could be incorporated into the computer game experiment to further assess how humans react to aspects of the motion camouflage strategy.

1. Introduction:

Man has been mimicking nature for thousands of years. With regards to camouflaging techniques, biomimetics research and development have been done in all the following areas: passive camouflage, warning coloration, active camouflage (optical camouflage being one type of active camouflage), translucent camouflage, reflecting camouflage and motion camouflage. Potentially of interest to both military engineers and to computer game developers, motion camouflage is a strategy from nature that is being studied by a research team at the University of London. Adapted from a study done by Srinivasan and Davey (1995), motion camouflage is a technique by which the 'shadower' pursues another moving body but remains unnoticed because the shadower gives the impression of remaining motionless.

Srinivasan and Davey studied the male hoverfly who used an approach along a particular set of constraint lines in order to unobtrusively approach the female of the species. These constraint lines are defined by two points: (1) a fixed point, which could be a distant, stationary object (like a rock) or the origin point of the shadower's flight path and (2) the current point of the object being pursued (as depicted in Figure 1):

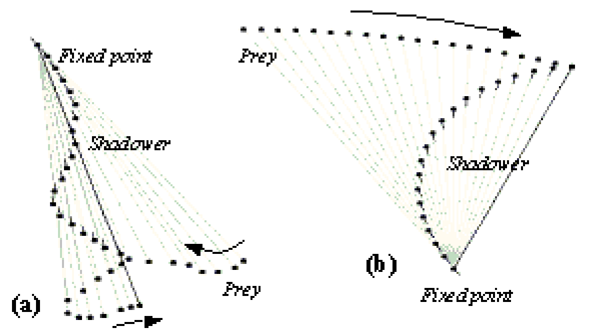


Fig. 1. Camouflage trajectories showing a simulated shadower approaching prey that moves along **(a)** the flight path of a real hoverfly **(b)** a regular arc. The shadower is depicted by the dots with tails, the prey, the dots without. At each instant the shadower is expected to lie on the line joining fixed point and prey.

Because the shadower is continuously attempting to maintain a position on the line between the fixed point and the prey, the shadower maintains its position on the prey's retina relative to the environment. The shadower becomes apparent to the prey (if the strategy is successful) only when the shadower's change in size becomes noticeable to the prey. The process of 'size revealing an object' is known as looming.

As an aside, one could mention that looming seems to be a threatening action to humans as well. It is a technique that has been employed in innumerable fright films: the slow, inexorable pursuit of hapless victim until the attacker, in what seems to be almost leisurely pursuit, grows onto the screen and overwhelms the victim. Perhaps deep in the human psyche there is recognition of motion camouflage as being an effective attack strategy. The following game was developed to show that humans, indeed, are susceptible to this strategy and respond less effectively to this type of attack than to a direct pursuit.

2. The Game

This game has been described, in detail, in “Motion camouflage deceives humans”, Anderson and McOwen. In the game, the player takes the role of prey; the missiles take the roles of predators. There are four different types of missiles with four different approach strategies:

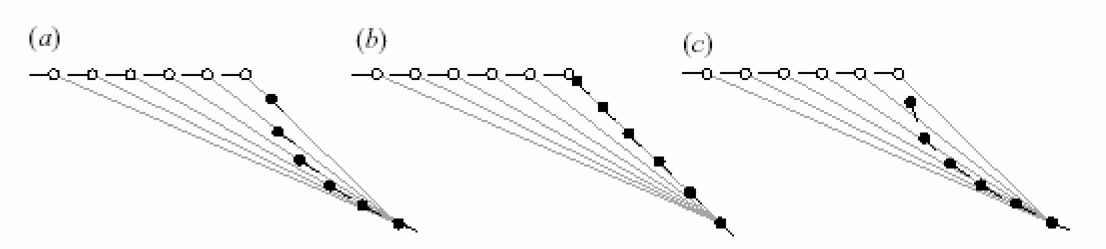
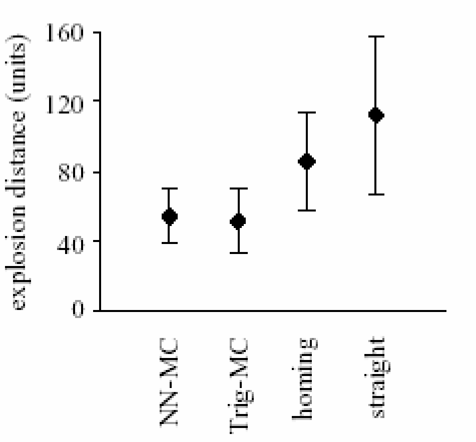


Figure 2 – Path Types

Missile Type:	**Approach:**
(a) Trig-MC (Trigonometric Missile Control)	Perfect, pre-calculated motion-camouflaged approach
(a) NN-MC (Neural Network Missile Control)	Motion-camouflaged approach calculated real time by the artificial neural networks developed by the team.
(b) Homing Missiles	Movement in the direction of prey at each time step.
(c) Straight Missiles	Movement in a straight line to intercept prey as quickly as possible

Table 2 – Missile Types

Each missile is launched from a missile launcher which acts as the missile’s fixed point. There is a penalty for shooting a missile launcher and for being hit by a missile. There are rewards for destroying a missile and a bonus for fast shooting. Effectiveness was determined by the distance at which a missile was exploded.



The above graph is a comparison of the mean +/- standard error explosion distance for the missile types. The motion-camouflaged missiles clearly were able to move much closer to target before being exploded. The conclusions made were that motion-camouflaged approaches were more effective in deceiving humans than homing or straight attacks. The least mean explosion distance/ per missile type/ per player was given by the motion-camouflaged missiles in 87% of the cases.

3. The Simulator

The simulator described below was the system used in the computer game. The stochastic 3D component* of the simulator controls the missile movements for the NN-MC (Neural Network Missile Control) in the game. The details of this simulator are found in "Model of a strategy to camouflage motion", Anderson and McOwen. A summary of these details are presented in Section 3.

3.1 Motivation for the experiment

The developers of this system sought to answer two primary questions and one secondary question with their experiment:

(1) Were the control systems able to make successful predictions of prey motion?
(2) In a test situation, would the control systems be able to approach prey that was moving in a different way than the training patterns?
(3) The developers were also interested to see if the system could be successfully trained.

3.2 Architecture

The architecture of the system consists of three predictive, dynamic, multilayer, supervised perceptron neural networks. This type of neural network is one of the more commonly-used ANN structures. The Dist network calculates distance to the fixed point. The Dir network calculates the direction the shadower must move. The Rot network calculates the rotation the shadower must perform to point radially away from the fixed point and to point directly toward prey. Distance, direction and rotation are each represented by a pair of values, the azimuth and elevation (a, e) in a spherical coordinate system. These three outputs are designed to move the shadower into camouflaged positions as close to the prey as possible.

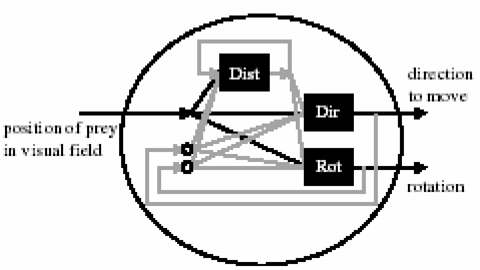


Figure 3 - Architecture

Process Steps in Neural Network:

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For each time-step in trajectory
        Input (a, e**) of prey in visual field - PreyPos
        Retrieve direction (a, e), distance (a,e), rotation (a,e) for past 3 outputs -  PosStats[3]
        Estimate current distance (a, e) - CDist
        Pass (PreyPos, PosStats[3],CDist) to direction network to estimate current direction (a, e)
        Pass (PreyPos, PosStats[3],CDist)  to rotation network to estimate rotation (a, e)
Next time-step
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Four neural networks were built for four different trajectory types:

Trajectory Type:	Detail:
Hoverfly 2D	Normalized from filmed, hoverfly flight paths
Regular 2D	Regular arcs developed in 2D space
Stochastic 3D	Randomized flight paths simulating hoverfly flight in 3D
Regular 3D	Regular arcs in 3D space

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*As opposed to the 2D hoverfly system. Simulation needed to show both lateral movement and approach toward prey.
** elevation only calculated for 3D systems

3.3 Training Process

Training used a standard back-propagation learning rule with momentum and learning rates selected empirically. Each of the four systems was trained as follows:

Multiple input and output pairs (a, e) for a given flight type were presented to a system for training. An input/output pair was submitted at each time step and 10^8 time steps were run for each system. Periodically, configurations were examined and the best-performing from this subset was selected as the final state of the controller. Configurations were extracted at random starting points and the accuracy of a set of steps was measured by the mean azimuth movement direction error.

3.3 Testing Process

As described in 3.1 the two motivations for the experiment were to see if a system would correctly predict movement in its own genre of path and also in a path type for which it had not been trained. Therefore, the 2D control systems were both tested using 2D regular prey trajectories and 2D hoverfly prey trajectories. The 3D control systems, in like fashion, were tested on both 3D regular prey trajectories and 3D random prey trajectories.

Results were also generated for a non-predictive shadower in order to have a basis for comparison. The non-predictive shadower moved in such a fashion as to always be camouflaged at the previous time step (t-1).

3.4 Results

In almost all cases the control systems were able to calculate accurate offensive, motion-camouflaged approaches. Visual, azimuth and elevation mean and median errors were recorded for all scenarios (predictive, same-type flight path; predictive, different-type flight path; nonpredictive, same-type flight path; nonpredictive, different-type flight path).

In the same-type flight path tests, the average error of the control systems, was, with one exception, less than the error given without prediction. The mean visual error for 3D predictive, same-type flight path was slightly greater than the nonpredictive counterpart. The authors attribute this to the greater difficulty in tracking prey movement in three dimensions. This is touched upon again in the commentary as not sufficient explanation for the error.

The second set of analyses (on different-type flight paths) showed, predictably, that those systems, trained on simpler (regular) flight paths did not respond robustly to the more complex (hoverfly and stochastic) flight paths.

4. Mathematics

The article by Glendinning, “The mathematics of motion camouflage”, published approximately 6 months after the previous two articles were published, presents ideal motion camouflage equations permitting computation of accurate motion camouflage paths.

4.1 Ideal motion camouflage equation

Glendinning, following on the heels of Anderson and McOwen, proposes a formula for ideal motion camouflage paths. He attempts to provide a theoretic framework so that these paths may be constructed without having to rely on control methods or discrete time observations (choosing the past three shadower positions to estimate the next, as we saw in Section 3.2). Once a formula is obtained it can be used as a tool for comparison and for application to new motion paths.

His first formula depicts a relationship between prey position, shadower position and fixed point position:

$$r(t) = r(0) + u(t)(z(t)-r_0)$$

where r(t) is shadower’s position; r_0 is fixed-point position; z(t) is prey position; r(0) is the starting point of shadower on first constraint line. He seeks the continuous function u(t) where its value falls between 0 and 1. When u(t) = 0 the shadower is at the starting point. When u(t) = 1 the shadower is at the capture point. Differentiating u(t) with respect to time, squaring both sides to eliminate the unknown velocity r , then taking the square root yields the quadratic equation for u(t):

$$du/dt = (-[(z(t)-r_0)dz/dt]u + \mathrm{sqrt}([(z(t)-r_0)*dz/dt]^2u^2 – (v^2u^2 – c^2)z(t)-r_0|^2))/|z(t)-r_0|^2$$

where v=|dz/dt| and c=|dr/dt|

4.2 Equation used as a tool for comparison

Now that there is a formula to calculate the motion camouflage path, one can use this formula to compare this type of pursuit path with other pursuit paths for which there are also mathematical treatments. In the article, Glendinning takes the well-known formula for classical pursuit strategy and develops numerical simulations where he compares the two types of paths. His analysis reveals several interesting results:

1. Both paths initially exhibit the same linear behavior. There is a phase where the strategies depart and where the motion camouflage path shortens.

2. The capture rate of the motion camouflaged path is consistently higher when predator speed>prey speed.

3. The motion camouflage strategy appears to be more efficient even when predator speed <= prey speed. This is “in the sense that capture is possible from a greater range of initial conditions”.

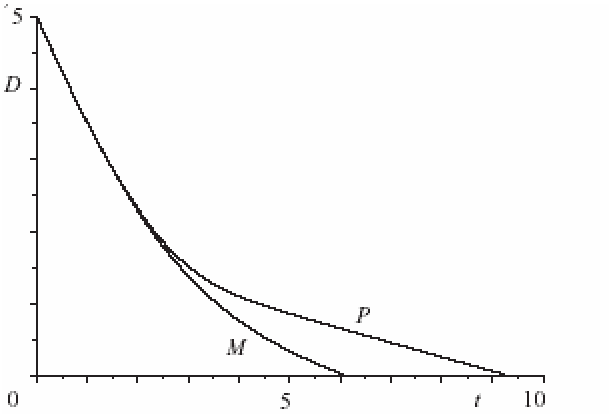

Figure 4: Time to capture of classical pursuit (P) vs. motion camouflaged pursuit (M)

4.3 Equation used on different type of prey trajectory

In addition to using the formula as a tool for comparison he also uses the formula to develop a motion strategy against more complex prey behavior. His selection of prey motion is the Rössler chaotic attractor in 3D. This is a more complex motion behavior and, although not explicitly stated, one that still has both prey and predator moving at constant velocity. In this experiment the target is moving faster than the aggressor. Despite this, the aggressor that follows the motion camouflaged strategy captures the target in 26.4 time-units. The aggressor that follows the classical pursuit strategy does not capture the target within the 200 time units.

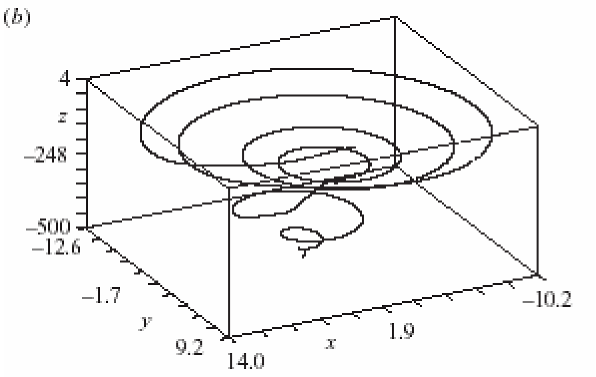

Figure 5: Depiction of chaotic attractor

Commentary:

The key insight that I gained from reading and studying these three papers is that the motion camouflage strategy is successful without the visual component. It is a strategy that will reach the prey faster than classical pursuit or homing. This is clear because of the results of the simulations recorded by Glendinning in his paper. Actually, Anderson in"Model of a strategy to camouflage motion" is not even testing the success of the strategy, only the ability of the control system to adhere to the strategy.

None of the experiments measured the success of the strategy due to the camouflaging component. So, in a sense, the camouflage component has not been analyzed. The strategy seems to be successful for reasons other than visual deception. One of the reasons seems to be the shortening of the motion camouflage path at a certain phase, as described by Glendinning.

In other words, Glendinning's tests were set up to gauge whether this pursuit strategy, because of the path taken, would overtake a target faster than other strategies. Anderson's game was designed to gauge the visual component, but questions remain. Are the players lagging in their response because of the key movement phase in motion camouflage strategy or because of the camouflaging effect? Perhaps the visual component does enhance the success of the predation but the experiments do not make this clear. However, the results do suggest that this is a successful pursuit strategy and I will present a list of ideas to increase understanding of this strategy including understanding of the visual component of the strategy.

Section 5.1 explores additional analyses that can be done using the existing game system developed by Anderson and McOwen. Section 5.2 suggests different games that could be created to gain understanding of this motion strategy. Section 5.3 explores an intuition for a different architecture for the control system that may lead to a more robust predictive system.

5.1 Additional tests with no or minor changes to the program:

Experiment 1. Is the effectiveness of motion camouflage due to flight path or camouflaging component or both?
Develop a set of motion camouflage flight paths. Run these simulations on constraint lines as missiles in the game. Run the same simulations slightly off the constraint lines so that the missiles are taking the same path but are not camouflaged. Record and compare the responses of the players.

Experiment 2. Is it valid to make the assumption that looming causes the player to notice the missile?
Evaluate the exact point at which players take note of motion-camouflaged targets. Is it when there is a change in the size of the missile or is it before this? No mention of this was made in the article but I think this is noteworthy. (I am making the assumption here that the visuals in the program do increase the size of the missiles on approach.)

Experiment 3: Part 1: How does change in the fixed point affect the player's perceptions?
In the motion simulation paper the control system was trained to respond by moving directly at prey should prey come between fixed point and shadower. Instead of opting to take a direct flight path toward the prey if the shadower moves between fixed-point and prey, change the reference point and see how this changes the prey's response.

Part 2: How does the change in fixed point affect the player's perceptions with regards to looming?
As looming takes effect, change the fixed-point to be closer to the moving shadower to see if this alters the perception of player.

Part 3: How does the change in fixed point on the horizon line affect the player's perceptions?
Create a visual horizon line. Let the missile following a motion camouflage strategy pick a fixed point on the horizon line. What happens if the fixed point is switched to other fixed points on the horizon line at certain intervals?

Experiment 4: Can we test more types of motion camouflage flight paths?
It is also known that the dragonfly uses a similar motion camouflage strategy. Mizutani et al have studied the dragonfly and note that one component of its strategy is to take a distant object as its reference point. Mizutani notes that this is a strategy that is equivalent to taking a fixed reference point at infinity, which is similar to the experiment outlined in Experiment 3, Part 3. Does the dragonfly use any other motion strategies that could be of interest?

Train and test a 2D and a 3D system on normalized dragonfly flight paths. Analyze the motion camouflage strategies of dragonfly vs. hoverfly. Also, research to see of there are any other animals that use or possibly use a motion camouflaging technique.

Experiment 5: Why was the 3D predictive, same-type flight path not as accurate as its corresponding non-predictive path?
In section 3.4 it was stated that the mean visual error for 3D predictive, same-type flight path was slightly greater than the nonpredictive counterpart. The authors attributed this to the greater difficulty in tracking prey movement in three dimensions. The authors developed a stochastic 3D equation because they had no information for the third dimension for hoverfly flight and had to make assumptions about this.
Replace the equation developed in Anderson's simulation with Glendinning's equation in 3D and observe the results.

Experiment 6: Can we study motion that is not at constant speed?
Glendinning states that the motion camouflage equation he developed can be extended to simulate a pursuit of prey that are NOT moving at constant speed. This would be very useful because this strategy could then be tested on many different types of movement for many different types of creatures.

Experiment 7: How does player respond if he is moving in different ways?
The player (in the role of prey) is moving in only a linear fashion down a tunnel in which the missiles are being launched. Have the player follow other movement trajectories, hoverfly, dragonfly, chaotic, other. Record success rates of striking various missiles in these situations.

5.2 Additional analyses requiring additional games

Experiment 8: Player as predator game
Develop a game in which the player can launch several different types of missiles toward targets. Record and analyze if and how quickly the player consistently chooses the motion camouflage strategy.
Prey can also use the motion-camouflage strategy as a retreat strategy which could be tested in a game where the player has taken the role of predator. Does the predator notice the retreat of the target that is moving in a motion-camouflaged way as quickly as it does other strategies for retreat?

Experiment 9: Find and catch the moving sea creature game
Animals can also use the motion camouflage strategy to move, unnoticed, from one place to another. One can test this in a game in which sea creatures are moving from one hidden spot to another. Test and record the responses of the player trying to catch the sea creatures.
Another part of this game could be to additionally camouflage the sea creatures with the other camouflaging techniques mentioned in the introduction. How does it affect a player's response if a creature is multiply-camouflaged?

Experiment 10: Team tactics game
Research into team tactics has already been proposed by Anderson and McOwen and can be found on their website listed in the References section of this document.

5.3 **Architecture:**

Several different types of architectures are available to support the development of a learning machine. SVMs have been shown to provide robust solutions to classification of data by taking nonlinear functions and converting them into a higher-dimensional space where boundaries can be processed linearly. Problems reduce to a quadratic programming problem with a unique solution. Time series predication applications make good use of SVMs.

Anderson's modeling article showed that the method of training did not allow for good generalization when any kind of complexity was introduced into the system (calculations for a third dimension, evaluation of more complex flight patterns). The promise and potential of support vector machines is to enable a system to generalize well. This application is very small and it would be a good research opportunity to see if SVMs did in fact enhance performance. We just touched upon this architecture briefly at the end of the course.

References:

Model of a predatory stealth behavior camouflaging motion, Andrew James Anderson and Peter William McOwan, The Royal Society of London, January 2003

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View from the Pennines: Nontrivial Pursuits, Paul Glendenning, July 2003

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Motion Camouflage, Anderson & McOwen, http://www.dcs.qmul.ac.uk/~aja/motion_cam.html

Motion Illusions and Active Camouflage, Lewis Dartnell, http://www.ucl.ac.uk/~ucbplrd/motion/motion_middle.html