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Humans deceived by predatory stealth strategy camouflaging motion

Andrew James Anderson* **and Peter William McOwan**

Department of Computer Science, Queen Mary, University of London, Mile End Road, London E1 4NS, UK
* *Author for correspondence (aja@dcs.qmul.ac.uk).*

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Motion camouflage is a stealth strategy that allows a predator to conceal its apparent motion as it approaches a moving prey. Although male hoverflies have been observed to move in a manner consistent with motion camouflage to track females, the successful application of the technique has not previously been demonstrated. This article describes the implementation and results of a psychophysical experiment suggesting that humans are susceptible to motion camouflage. The experiment masqueraded as a computer-game competition. The basis of the competition was a game designed to test the comparative success of different predatory-approach strategies. The experiment showed that predators were able to approach closer to their prey (the player of the game) before being detected when using motion camouflage than when using other approach strategies tested. For an autonomous predator, the calculation of a motion-camouflage approach is a non-trivial problem. It was, therefore, of particular interest that in the game the players were deceived by motion-camouflage predators controlled by artificial neural systems operating using realistic levels of input information. It is suggested that these results are especially of interest to biologists, visual psychophysicists, military engineers and computer-games designers.

Keywords: motion camouflage; stealth; neural network; psychophysics; computer game

1. INTRODUCTION

The use of camouflage is widespread throughout nature. Many species have evolved deceptive appearances, and, during the last century, the military have profited by camouflaging troops and equipment. This article concentrates on a different form of camouflage from that of camouflaging appearance. It concerns a strategy to camouflage motion. Motion camouflage was first suggested by Srinivasan & Davey (1995) as a technique that would allow a predatory body to camouflage its approach from a moving prey. The predator achieves this by approaching along a path such that its image projected onto the prey's eye emulates that of a distant stationary object (a *fixed point*). During its attack, the predator must ensure that it is always positioned directly between the current position of the prey and this fixed point (see figure 1*a*). The line joining the prey to the fixed point is referred to as the camouflage *constraint line*. For example, if the predator were to start its approach positioned in front of a rock, it would ensure that it is always positioned directly between the rock and the prey. The optic flow, i.e. the change in position of the image of the predator projected onto the prey's eyes, would then emulate that of the rock (see Lee (1980) for details of optic-flow fields). The prey would perceive no lateral motion (retinal slip) of the predator's image relative to the environment and it is therefore argued that the prey would be less likely to notice the approach. Srinivasan & Davey (1995) observed that male hoverflies adopted paths consistent with motion camouflage to approach females. To our knowledge, this is the only evidence of the application of motion camouflage collected to date. This article describes the implementation and results of a psychophysical experiment used to show that humans are susceptible to motion camouflage. The psychophysical experiment was disguised as a computer-game competition. The basis of the experiment was a three-dimensional computer game, Missile Defence, which was purpose written to allow comparison of the distances that different attack strategies would allow a predator to approach to before being detected.

2. METHODS

In the game, the player takes the role of the prey, which moves in a straight line down the centre of a tunnel. Floating in the tunnel are stationary missile launchers, which may or may not fire a missile at the prey (i.e. the player). From the experimental point of view, the missile launchers are the fixed points and the missiles are the predators employing different strategies (including motion camouflage) to approach the prey. The player's purpose in the game is to gain a high score by shooting the approaching missiles as fast as possible (to avoid being hit). Missiles and missile launchers are identical in appearance and are both represented as bright yellow spheres. The only methods by which the missiles may be distinguished from the launchers are by their pattern of motion (relative to the player's own movement) and their looming (the change in a missile's image size on approach; see Lee (1980) for coverage of how looming may be used to estimate time to contact with an object). All missiles have a limited range and explode after a fixed time period. The player is given the freedom to look and shoot in any direction (controlled by moving the mouse and clicking the mouse button) as is conventional in contemporary first-person-perspective computer games, such as Quake 3 (www.quake.com.br). One point is awarded for each missile shot and a speed bonus is awarded for fast shooting (the speed bonus encouraged players to shoot at the missiles as quickly as possible). Players lose two points each time they are hit by a missile and lose three points for shooting a missile launcher (the penalty for shooting missile launchers was included to discourage reckless shooting, e.g. attempting to shoot missiles before they have been fired).

There were four types of missile, categorized according to their approach strategy. (i) *Trig-MC* missiles adopted perfect motion-camouflaged approaches (calculated with advance knowledge of the exact locations of fixed point and prey using trigonometry). (ii) *NN-MC* (neural network motion camouflage) missiles also adopted motion-camouflage approaches. However, these missiles were controlled by autonomous artificial neural controllers (artificial computational systems inspired by biological nervous systems) developed by Anderson & McOwan (2003). These missiles were the only missiles not to calculate their path based on prior knowledge of the exact locations of prey and fixed point. The controllers were trained to perform motion-camouflaged approaches using realistic levels of input information (the only external information provided was the current direction of the prey). Anderson & McOwan (2003) demonstrated that similar systems had already been shown to be able to adopt accurate camouflaged approaches, demonstrating their ability to predict future prey positions and estimate the position of the fixed point using dead reckoning. (iii) *Homing* missiles moved in the direction of the forthcoming prey position at each time-step (see figure 1*c*). (iv) *Straight* missiles moved in a straight line to intercept the prey as quickly as possible, or get as close to the prey as possible, before reaching their maximum range and exploding at each time-step (see figure 1*b*). The effectiveness of each of the four approach strategies was measured in terms of the distance from the prey at which the missiles exploded (either through being shot, hitting the prey or self-

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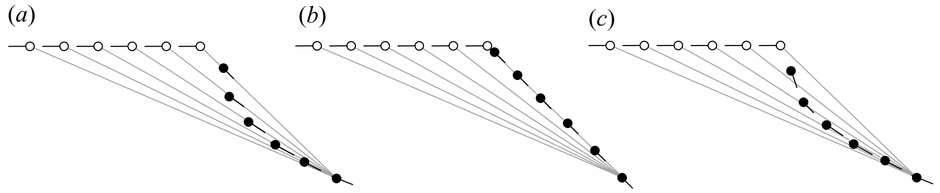

Figure 1. Example predator approach paths (shown in two dimensions); (*a*) motion-camouflage approach; (*b*) straight approach; and (*c*) homing approach. Predators and prey are represented as filled and open circles, respectively. Grey lines are camouflage constraint lines.

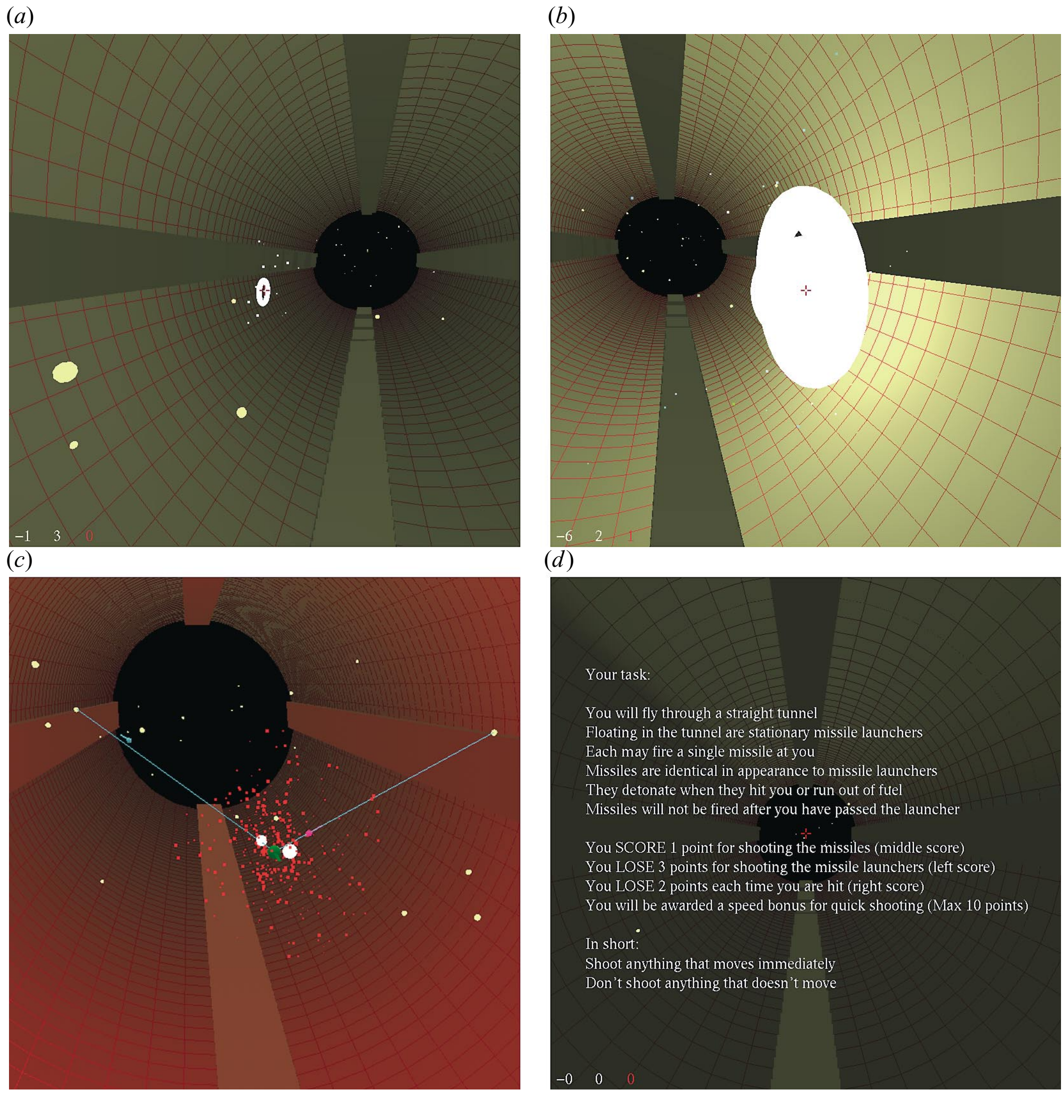

Figure 2. Missile Defence screen shots. (*a*) Explosion indicating when a missile has been shot. The explosion grows over five frames. The view is from the player's perspective. (*b*) Explosion indicating when a missile launcher has been shot. The explosion grows over 10 frames. The view is from the player's perspective. (*c*) Two examples of the explosion indicating when the player has been hit by a missile or when a missile self-destructs. White spheres mark the centres of the explosions. Similar to (*a*), these explosions last five frames. The view is from a third-person perspective (behind the prey). The player (prey) is shown in green in the centre of the image. For the purposes of illustration, the missiles are exposed. The light-blue sphere with a tail in the top left of the image is a straight missile. The pink sphere with a tail to the right of the prey is a Trig-MC missile (see § 2 for a description of missile types). The blue lines are camouflage constraint lines. (*d*) Instruction screen. The background is shown at normal luminance (without explosion lighting).

destructing after reaching the end of their life). Whether the player has hit a missile, shot a missile launcher or been hit is indicated by one of three explosion types, as shown in figure 2 (thus giving the player covert feedback of their success).

The experiment was conducted under the guise of a one-week-long games competition. Players were invited to compete for a prize for the best Missile Defence score. The 30 experimental subjects were all members of staff or students at the Department of Computer Science, Queen Mary, University of London, and competed voluntarily. At the start of each game, competitors were shown an instruction screen (see figure 2*d*). Competitors were allowed multiple attempts to beat the high score, though, to ensure equal representation of each competitor, the results from the competitor's best-scoring game only were selected for analysis (a mean of four games

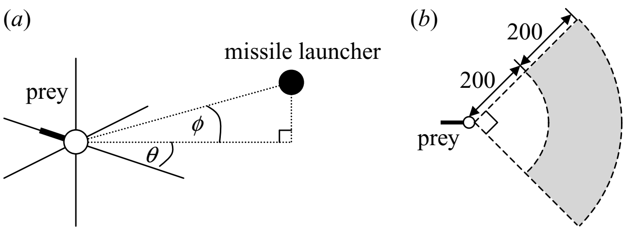

Figure 3. Location of missile launchers. (*a*) The azimuth θ and elevation ϕ of a launcher's position at firing relative to the prey were selected randomly from the ranges (measured in radians) $-\pi/4 > \theta < \pi/4$ and $-\pi/8 > \phi < \pi/8$ (if both angles are 0, the launcher is directly ahead of the prey). The distance between prey and launcher at firing was randomly selected from the range 200–400 distance units. (*b*) A plan view of the three-dimensional area (shaded grey) in which a missile launcher could be positioned relative to the prey.

per player were played). Subjects were unaware of the purpose of the experiment. Experimental parameters are listed below.

Subjects: normal or corrected-to-normal vision; age range of 18–40 years; distance of screen from player of *ca*. 50 cm. Game: number of missile launchers = 80; number of missiles = 40 (10 of each missile type); missile-launcher radius = 2 units; prey step size = 4.5 units; missile step size = 5 units; maximum missile lifespan = 40 steps; game window size = 19 cm × 19 cm; missile-launcher firing time was random over the game; game duration = 1200 steps (over 5 min). Note that in order to smooth the animation 10 extra frames were inserted between consecutive steps (positions of prey and missiles were calculated by linearly interpolating between steps). Each game therefore consisted of 13 190 frames. Missile launchers were located as shown in figure 3*a*,*b*.

3. RESULTS AND DISCUSSION

The results of the experiment showed that, in general, the motion-camouflage missiles approached closer to the prey than the other missile types. Figure 4*a* displays frequency distributions of all missile explosion distances (300 of each missile type, 10 per subject per missile type). The distance distributions corresponding to the two motion-camouflage missile types (NN-MC and Trig-MC) are very similar. These missiles were predominantly shot within 100 units of the prey and rarely shot beyond 150 units. By contrast, the range over which homing and straight missiles were shot was far greater, with homing missiles occasionally shot at distances in excess of 200 units and straight missiles often shot at distances of between 200 and 300 units. Figure 4*b* displays the mean ± standard error of the mean distance per player at which missiles exploded. The data shown in figure 4*b* were log transformed to reduce heteroscedasticity (inequality of sample variances) and analysed using a one-way analysis of variance (d.f. = 119). The analysis indicated a highly statistically significant difference between missile types. *Post hoc* least significant difference tests indicated that there was no significant difference between Trig-MC and NN-MC approaches ($p = 0.43$). There was a highly significant difference between any combination of motion-camouflaged approach and non-motion-camouflaged approach ($p < 0.0001$). Finally, there was a significant difference between the homing and straight approaches ($p = 0.02$). The mean distance at which NN-MC missiles exploded was 0.63 times that at which the homing missiles exploded and 0.48 times that at which the straight missiles exploded. The lowest mean explosion distance per missile type per player was for the motion-camouflaged missiles in all but four out of the 30 cases.

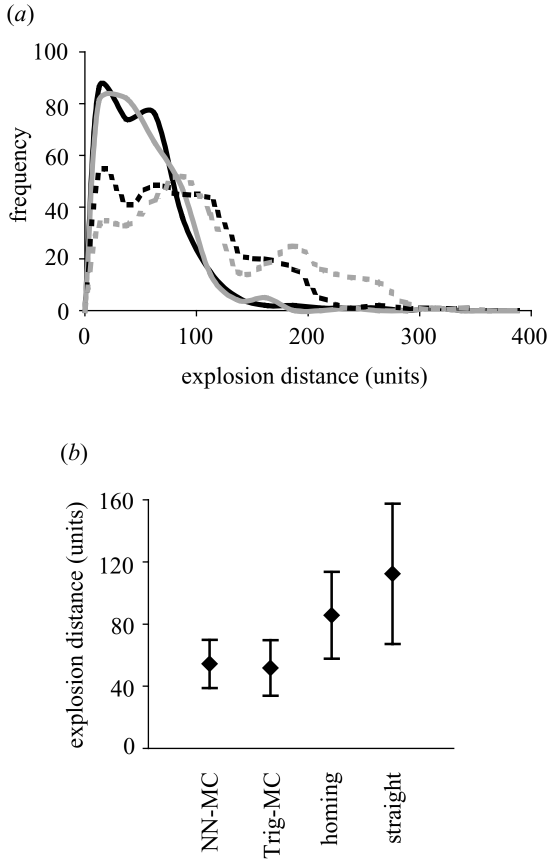

Figure 4. Explosion distances. (*a*) Comparison of the frequency distributions of raw explosion distances for each missile type. Black line, NN-MC; grey line, Trig-MC; dashed black line, homing; dashed grey line, straight. (*b*) Comparison of the mean ± standard error explosion distance for each missile type.

Concluding, this article has shown: (i) that the majority of the experimental subjects were susceptible to motion camouflage, thus showing for the first time that humans are susceptible to motion camouflage; and (ii) that it is possible for artificial systems to calculate motion-camouflaged approaches sufficiently accurately to deceive humans in a practical task. In so doing, this has further validated the control-system architecture presented by Anderson & McOwan (2003). It is suggested that these results may be of interest to biologists, visual psychophysicists and military engineers. The article has also demonstrated a potential application of motion camouflage as an approach strategy for controlling predatory agents in computer games.

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