Effects of standardised quadcopter flight patterns on foraging birds
a test case for autonomous data gathering in ecological research

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Graduation Thesis, June 2016
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Abstract - **The quickly increasing prevalence of Unmanned Arial Vehicles (UAV's), will have animals confronted with them in unexpected ways. In this paper it is argued that research concerning interactions between animals and UAV's, should be developed from a perspective of scalable, autonomous, data gathering. A research setup that is designed from that perspective, with a focus on birds, is presented and its feasibility as a successful data gathering setup is assessed by means of a test case. This test case shows, that in response to quadcopter flight, carrion crows avoid a foraging site, egyptian geese are unaffected, and eurasian magpies and jackdaws shorten their visit duration. As this successful test case supports usability of the proposed setup, current shortcomings and future opportunities in this direction are discussed.**

Keywords: Animal-robot interaction, animal welfare, UAV, bird disturbance, scalable research, autonomous data gathering, citizen science

1. The emergence of animal-UAV interaction research

Animal-robot interaction is a field of growing interest in which an increasing amount of successful studies are being conducted. For example, robotic cockroaches that were accepted as conspecifics (based on odour), have been used to investigate the mechanisms of communal shelter seeking in cockroaches [1]. Multiple experiments with robotic fish have been carried out to investigate a range of topics, such as cooperation in predator inspection [2], collective movement decisions [3] and mechanisms of recruitment and leadership [4]. In another study, a rat-like robot that simulated stressful and friendly behaviour was used to investigate how it influences real rat behaviour [5].

These studies developed robots with the aim to imitate the animal that was being researched. This technique of imitation, has proven to be useful for testing existing hypotheses about animal social behaviour. Rather than trying to imitate a complete animal, another approach is designing a robot that evokes certain stimuli that trigger an animal.

For example, an autonomous mobile robot with a heat source that attracted quail chicks, was used to gain insight in the role of spatial experience on behavioural development [6]. In another research Vaughn et al. used a robot that repelled a flock of ducks to study automatic flock control [7].

Recently Unmanned Arial Vehicles (UAV's) have made their way into wildlife research. Ecologists are steadily welcoming this affordable and comprehensible piece of technology, to use in surveying and observing animals [8, 9]. The effects that these UAV's might have on wildlife, is the subject of a number of recent studies.

Research concerning bears that were being approached by UAV's, found a stress response in the form of an elevated heart rate [10]. A study in which different types of UAV's flew over groups of grey- and harbour seals, resulted in very diverse disturbance reactions. The study was inconclusive as to what caused the variances among the test cases [11].

This last type of research emerges as a new category within the animal-robot interaction field, since the robots that are being used, are not specifically designed to be interacting with animals. The robots are in the first place created for a variety of human applications and make their way into the field of animal behaviour *by accident*. They are not designed with knowledge about stimuli that trigger animals in mind. A helpful way to think about these robots in an ecological context, might be to describe them as an entirely new species.

2. Why study animal-UAV interaction?

Driven by increasingly cheap sensor technology and advancements in controlling software, the market of UAV's will be booming in the coming decades [12-14]. This flying potential has proven to be enticing, and the ideas that companies and researchers have been keen to show off, are being met with an enthusiastic mainstream interest. Parcel delivery, human transportation, construction and first aid are a few among the many possibilities that are actively being explored [15-18].

2.1 Animal welfare

This predicted scale of prevalence, combined with the move of this technology towards increasing autonomy, enforces the notion of a "new species", with which animals inevitably have to deal. Given that we appreciate and respect animals in the way they are currently interwoven with our society, taking steps to assure future continuation, potentially reinforcement, of this relation is very valuable [19]. In the case of the advent of UAV's, this will require regulations and technical solutions that take animals into account. Thinking about this in a meaningful way requires insight in the ways animals react to UAV's.

2.2 Ecological neutrality

From an ecological-research perspective there are two main reasons to learn more about animal-UAV interaction. Firstly, employing UAV's during studies asks for ethical guidelines which assure that the animal under scrutiny is being respected. Secondly, it is desirable to learn when an UAV can be excluded as a confounding factor during behavioural observations.

2.3 Animal control

If animal response to UAV behaviour could be predicted, one could take a programming approach to animal control problems. Handling cattle, protecting crops, entertaining pets [20] and clearing aviation zones, are examples of areas where such an approach has potential. The increasingly lowering price due to economies of scale and the environment independent flexibility of UAV's, set them apart from other automation solutions.

3. How to study animal-UAV interaction?

Gathering data within ecological research is a notoriously complicated process. It traditionally takes a lot of time and expertise to gather useful amounts of data. This has to do with the fact that ecological research takes place in a chaotic and uncontrolled environment, i.e. nature. UAV's are well equipped to handle the physical side of this chaos, since they rely on air to travel in, can hover in place and are capable of precise manoeuvring. Making sense of this environment, i.e. conceptualising nature, is recently starting to arise as a technical possibility, because of increasing-computer-power-driven applicability, of advancements in the field of computer vision [21, 22].

UAV's and computer vision algorithms combined, offer an unprecedented research tool that has the potential to revolutionise the research field by making data gathering less sluggish. Effectively utilising this new research tool requires a different view on setting up a research; developed from the robot's perspective, instead of the human perspective.

When setting up a research with a human observer in mind, the types of data one can gather are almost unlimited, but the amount of data is very much restricted. We propose to develop research methodologies with autonomous technology in mind. In that case, the constraints of the methodology will be dictated by the constraints of the technology. In other words, the types of data one can gather will be limited. But, at the same time, the amount of data that can be collected will hugely increase. Developed autonomous technology doesn't require slowly acquired ecological expertise, is scalable and doesn't sleep. Because of these qualities, autonomous research technologies also offer a lot of potential within the blossoming field of citizen science [23-25]. By employing this approach we promote *scalable research*, targeted at acquiring large datasets.

The value of acquiring large amounts of data is twofold: Firstly, larger datasets increase the chance of finding statistically significant results. Secondly, animal behaviour is complex and dependent on an interplay of a wide array of factors. In this sense it shares properties with fields like semantic vision and human language. Deep neural networks have shown to be of great help in getting a grip on these fields [26, 27]. This type of algorithm relies on vast amounts of data. Gathering ecological data on a large scale could aid the development of animal behaviour targeted, neural networks [28].

Obeying this reasoning, this research is developed with a focus on chances for scalable, autonomous data gathering. The research itself is a means towards the end of exploring the viability of this approach.

4. Focus on birds

We focus on birds as a study subject within the animal-UAV interaction field since (1.) they will be most drastically confronted by UAV's and (2.) bird-UAV interaction knowledge is needed most urgently. The former because the spread of UAV's entails an airspace invaded by human technology, a domain that, up till this point, has mainly been exclusive to birds. The latter because birds are the only wild animals we consciously share our cities with, and sustaining that relation requires timely insight into urban developments which might destroy it.

4.1 Bird disturbance

Bird disturbance in general has been widely studied. From the literature four indicators of measurable disturbance can be distilled:

1. Physiological effects such as increased heart rate and changes in hormonal activity [29-31].
2. Changes in behaviour such as a visibly higher state of alarmedness and flight behaviour [32, 33].
3. Changes in feeding patterns and energy management [34-36].
4. Influence on survival and reproduction [37, 38].

The studies showed effects on these indicators in response to a variety of approaching entities, such as humans, cars, helicopters and boats. Furthermore, different movement conditions such as approach speed and angle were shown to have their own specific effect.

We found two disturbance studies that specifically focused on UAV's and birds. In one, researchers would approach birds repeatedly with a UAV and changed colour, speed and flight angle of the UAV between flights [39]. Mallards, flamingos and common greenshanks could be approached seemingly unaffected to within 4 meters during 80% of the flights. Colour, speed and repeated flight had no measurable impact, but approaching birds vertically did trigger some disturbed behaviour. In the other study, a research team looked into the effect different models of UAV's had on waterfowl [40]. They found little disturbance when the rotor models (as opposed to fixed wing planes) were flown 40 meters above the birds. At lower altitudes, disturbance was starting to become apparent.

From these studies it seems that the effects of UAV's vary per species and that the flight style has an effect. Within this research we take an autonomy focused approach on the hypothesis that *the presence of an airborne UAV will have a species specific effect on all four disturbance indicators and the UAV's flight style will have consequences for the scale of those effects.*

5. Iterative design of the method

5.1 Autonomy based initial setup

A general research setup addressing the hypothesis was designed from the perspective of autonomous data gathering. We looked for opportunities of scalable automation that can be achieved with relatively easy to acquire technologies. Due to technical and practical complexity, automating the measurement of physiological effects doesn't fit in this category. Influence on survival and reproduction rate might be feasible, but not within the timeframe of this research.

However, the visually detectable changes in behaviour and changes in feeding patterns do provide a good starting point for scalable automation. The initial proposition for the research setup is shown in figure 1.

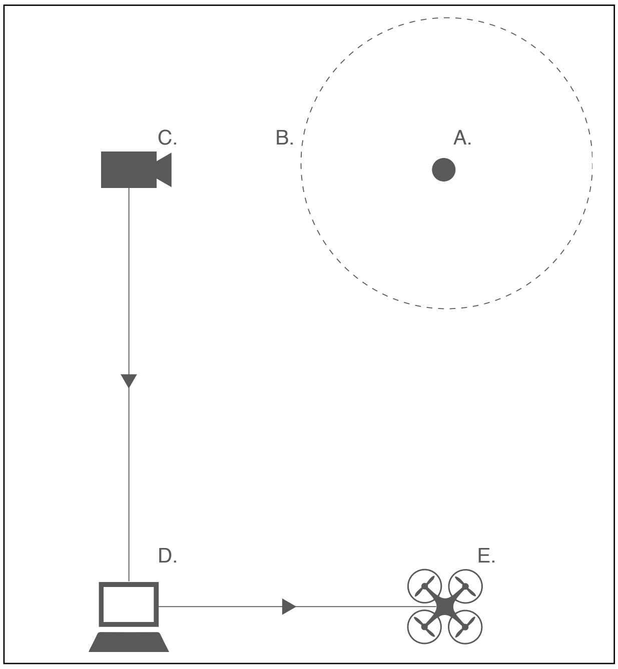


Figure 1: Food is placed in a container (A). A camera is setup facing the food (C). When a bird comes within a certain range (B) of the food, a computer (D) detects the movement from the camera's video stream. This will trigger a UAV (E) to start an automated standardised flightpath. Bird behaviour in response to this will be recorded. The UAV ends on its take off position. This sequence repeats itself as long as needed.

The purpose of a single food source is twofold. Firstly, since the location of the food source dictates where the birds will likely be active, it will be clear for the system where to look for incoming birds. Secondly, it gives the UAV a clear and fixed reference point for its automated flightpath. Recordings of birds approaching the food and their reaction to the UAV offer potential for automated analysis. Ideally, this whole setup could collect and process data autonomously, with only the need of human intervention for placing food, changing batteries and general maintenance. What follows is a description of the iterative exploration of this ideal, cumulating in the actually employed research method.

5.2 UAV choice

Within the category of UAV's it are especially the multicopters that have a lot to offer for this type of scalable research. As opposed to fixed wing models, they can easily take off in almost any kind of environment. Furthermore, most pre-built multicopters are equipped with an infrastructure, in terms of sensors and cameras, that cater to the requests of autonomy enabling software. Using a custom made multicopter might yield a superior price/performance ratio, but the time and knowledge needed for such an endeavour would mean that this option is not easily scalable. Although the choice of using a pre-built multicopter narrows down the options quite a bit, there is still an abundance of possibilities within this category. At this point the Parrot line of quadcopters offers the unique advantage of being easily hackable. This has to do with two, each other reinforcing, factors: firstly, Parrot offers an SDK (Software Development Kit) for its quadcopters. Secondly, there is an enthusiastic community of people writing code for Parrot quadcopters.

Conclusively, within the product line of Parrot, the relative affordability of the Parrot AR.Drone 2.0 (440*440*85 mm, 400 gram) assured its selection for this research.

5.3 Autonomous flight

Quadcopters can autonomously fly sideways through small rectangular openings, build a rope bridge and work together to catch a ball [41-43]. This is achieved by using static motion capture systems and markers to track the position of the quadcopter within its environment. As much as this approach offers in terms of precision, it lacks in flexibility.

A more flexible, and as such scalable, approach of state estimation is provided by Simultaneous Localisation And Mapping (SLAM) methods, which rely on the use of onboard sensors. This subcategory of computer vision is very turbulent; much progress is still being made, standardisations and best practices are still up for discussion.

We decided to explore the feasibility of the "tum_ardrone" software package for the envisioned research setup. This software package developed at the Technical University of München, employs a SLAM based approach and was designed specifically with the onboard sensors of the Parrot AR.Drone in mind [44-46]. Furthermore, it runs within ROS (Robotic Operating System), a set of libraries and tools which makes keeping an overview and adding to existing code relatively easy.

5.3.1 Indoor testing

Gradually becoming the standard in the robot development community, with an emphasis on sharing, ROS lets you tap into the knowledge of numerous high quality robotic projects. The ROS environment can be installed on a system running Ubuntu.

Once the "tum_ardrone" package was installed within the ROS framework, numerous indoor tests were carried out. For the SLAM system to work properly a 3D point cloud had to be generated. This could only be done when the quadcopter was flying. The resulting point cloud could not be saved and used for later sessions. This made testing a strenuous task. Once familiar with the quirks of the system, it worked well in a variety of indoor settings ranging from a small living room with many obstacles (15 m^2) to a big gym with view reference points (1380m^2). The quadcopter was able to autonomously perform quite extensive flight manoeuvres, using only its onboard sensors and a laptop's calculation power.

5.3.2 Outdoor testing

Outdoor testing proved to be more problematic then expected. It was very hard to establish and retain a useful 3D point cloud. This could be attributed to a number of factors:

1. Wind conditions meant that establishing the 3D point cloud would always take place under more turbulent conditions then those inside.
2. The natural shapes that are to be found outside are less easily recognised then the artificial structures tested with inside.
3. Changing parts of the environment such as moving leaves, clouds and fluctuating light conditions create a dynamic environment.

We tried to overcome some of these limitations by testing close to a wall with a clearly deductible pattern. Furthermore, black and white checkerboard patterns (420*594 mm) were hung, to serve as reference markers. Although this did yield slightly better results, we weren't able to repeatedly establish a sufficiently reliable 3D point cloud.

5.3.3 Autonomous flight conclusions

The "tum_ardrone" package was indeed a suitable and flexible solution for state estimation indoors, but its potential crumbled when working outside. At this point in the project, we chose not to pursue any alternative and instead emulate autonomous flight behaviour. Other options like using a different SLAM software package or a combination of GPS and markers might turn out to be workable, but would also be very time consuming to implement. The focus of this research lies on investigating the usability of the data one might gather with a setup that lends itself for automation, not on testing every possible instance of the underlying technology. Furthermore, many professional players are currently developing their own SLAM based solutions (hololens, project tango, leap motion). The test projects that they are demonstrating show significant improvements over currently available options, including promising results for outdoor testing [47]. Therefore, we expect that it is a matter of little time before implementing these types of algorithms is much more easy and effective.

Table 1: Preliminary bird response research

Number of trials	Species	Mean number of birds (st. dev)	Mean fly off dis.t in meters (st. dev)
5	Jackdaw	8.6 (12)	42 (23)
4	Greylag Goose	6.4 (3)	25 (17)
3	Mallard	3.7 (1)	n.a.
3	Common Wood pigeon	2.3 (2)	23 (20)

5.4 Bird detection

Assuming exclusively movement by birds around the food source, we explored the option of movement detection as a way of triggering the quadcopter to start its automated flight path. Code (based on the OpenCV library) that detects movement from incoming imagery of a camera was developed. By using ROS, which is designed to easily understand and add to unfamiliar projects, the bird detection code could be integrated within the "tum_ardrone" package with relative ease. Detected movement would trigger the Parrot AR.Drone to perform one of its predefined flight manoeuvres. However, when the choice for emulating autonomous behaviour was made, the option of automatic movement detection was suspended.

5.5 Preliminary bird response research

An informal preliminary research was conducted, with the goal of finding a location that was suitable, in the sense that birds would be attracted by food and the attracted birds showed a visually measurable reaction to quadcopter manoeuvres. This was done by analysing what type of birds were attracted during food placement tests and noting behavioural responses during quadcopter flight tests. Based on this low key research we established some guidelines that would help to inform the specification of the method.

5.5.1 Quadcopter flight tests

When foraging birds were spotted during a scouting session, the Parrot AR.Drone drone would be setup and, in order to provide some sort of null condition, some minutes of quiet observation would follow. Birds would continue foraging during the observation, but a visible response was found in all the birds confronted with the quadcopter (Table 1). The types of response wildly varied for different species. Geese regularly responded with distressed calls, followed by flight behaviour towards nearby water. Jackdaws were seen to fly off at relatively large distances. Common wood pigeons responded quite randomly. Mallards usually acted somewhat disturbed when the quadcopter came very close, but never chose to fly off. We did not test

Table 2: Preliminary location research, each trial lasted 1 hour

Number of trials	Location	Mean birds p/h (st. dev)
7	Museumpark Rotterdam: 51°54'43.488N, 4°28'23E	- 0.6 (0.8) Eurasian Magpie - 2.4 (1.7) Jackdaw - 1.4 (1.3) Common wood pigeon
5	Euromastpark Rotterdam: 51°54'17.591N, 4°28'16.593E	- 4.6 (2.1) Eurasian magpie - 9.2 (1.9) Jackdaw - 2.6 (0.6) Crow

with seemingly obvious choices such as seagulls or domestic pigeons, since they were usually to be found in areas that did not really offer good opportunities for undisturbed drone flight research.

5.5.2 Food placement tests

In light of research which found that foraging behaviour among birds is usually more intense in the morning [48] and in an effort to minimise human disturbance, food placement tests were usually executed in the early morning (before 8.00 am). We tested with two types of food; mixed seeds and mealworms. Since the presence of birds around the food source seemed to attract more birds, and both food types had overlapping audiences, using the two food types in tandem resulted in an exponential increase of attracted birds. Although being aware of the fact that simultaneous placement of two different food types would decrease insight in specifications of the feeding patterns, increasing the size of the potential test populations was preferred in this trade off.

5.5.3 Location tests

A suitable location, that attracted a satisfying amount of birds and showed minimal human disturbance, was found in the Euromast Park in Rotterdam (Table 2). A grass field, with occasionally a tree providing shelter to a variety of birds provided the necessary conditions in which both the quadcopter could fly and birds were prolific.

5.5.4 Sound tests

An effort was made to investigate, wether the sound the quadcopter produces, would be a confounding factor. The sound of a quadcopter taking off and flying towards a recording device was recorded. In a number of feeding sessions, a wireless speaker was placed in close proximity (~4m) to the food source. When a few birds had gathered around the food source, the recording would be played on the speaker. This did not seem to lead to disturbance; gathered birds were never seen to fly off in response to this. Some species (especially eurasian magpies) did display inquisitive behaviour towards the sounds origins, as they approached and investigated the noisy entity. Because of these findings, we decided not to implement the speaker in the null-condition of the final research setup, though it has to be stressed that no strong claims can be made on the effects of UAV sound on bird behaviour.

6. Method

Starting May 14th 2016, a scattered hand of 150 gram mixed seeds (sunflower, corn, pros millet) and an open plastic container (10 * 10 * 4 cm) containing 80 gram of living mealworms were placed daily, 45 minutes after official sunrise time, on an open grass field in the Euromast Park in Rotterdam, the Netherlands (51° 54' 19N, 4° 28' 10E), allowing foraging birds in the surrounding environment to learn about the reliable presence of the food source.

After a week (21/5/2016) food was placed in the same fashion, but now a non-rain, non-extreme-wind day (the weather conditions in which the quadcopter used in this research could fly) would alternately result in either an observation day (null condition), a drone flight observation day category I (test condition 1) or a drone flight observation day category II (test condition 2).

All conditions share the same base setup, expanded upon with their own characteristics as described below. Mentioned distances were determined relatively to existing landmarks, avoiding the need for possibly obtrusive artificial landmarks.

6.1 Base setup

A camera (Xiaomi Yi, white, all indication lights turned off) on a tripod was installed at a distance of three meters of the container with mealworms. When the food was placed, the camera was turned on, a recording was started, a timer was started and the observer would face the setup at a distance of 95 meters. After one hour the setup would be taken down, mealworms that were still left in the feeding container were weighed.

6.1.1 Observation day (null condition)

After 45 minutes the observer would move around in the same fashion as would be the case when replacing a battery during a drone flight observation day.

6.1.2 Drone flight observation day (test conditions I & II)

A Parrot AR.Drone 2.0 was placed near the observer at a distance of 90 meters from the food source. As soon as a bird would enter within a two meter radius from the container (an inflight), a laptop or phone (the laptop

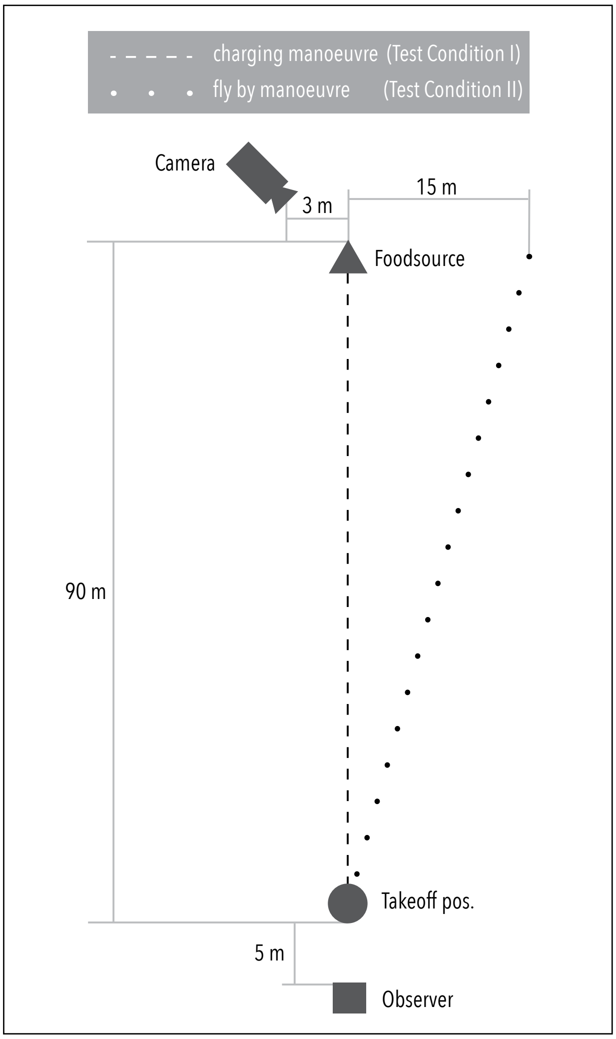
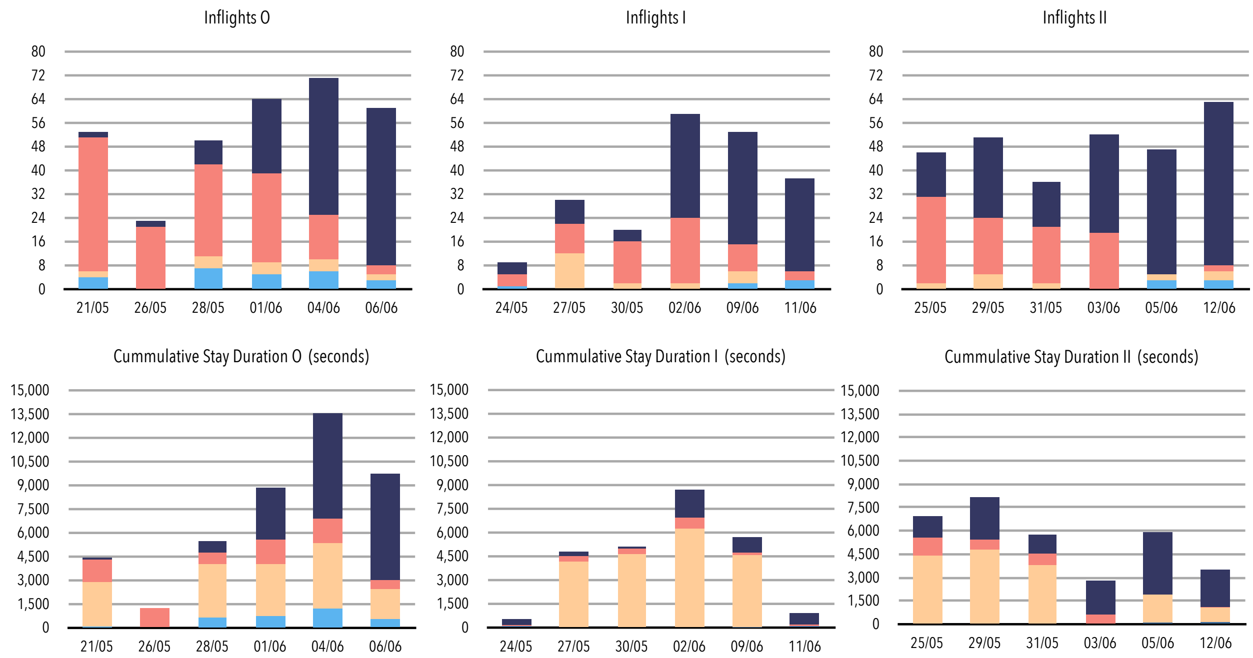


Figure 2: Schematic overview of the research setup.

ran into technical problems during the fourth day of the research and was substituted by a phone) would be used to control the quadcopter and perform a standardised flight manoeuvre of either category I (test condition I day) or category II (test condition II day) at a height of 2-3 meters (Figure 2). Both of these manoeuvres ended with the drone landing on its take off position. Birds that were still within a two meter range from the container at this moment, would be ignored for the time being and only new inflights would trigger repetition of a flight manoeuvre. This rule was established because without it, birds not leaving the established radius in response to quadcopter flight would continually trigger flight manoeuvres. This would result in an experiment that is triggered by subjects that are least effected (at least visually) by its stimuli, which is an unfortunate situation. Furthermore, this would demand strenuous amounts of battery power and the resulting frequently needed battery replacements during experimentation are an unwanted nuisance for clean data gathering.



legend:
Carrion Crow · Egyptian Goose · Eurasian Magpie · Jackdaw

Inflight: An approaching bird would be counted as an inflight when it entered within a 2 meter radius from the container with food

Duration of stay: the time between the inflight and leaving the 2 meter radius

Figure 3: Results of testing between May 21h and June 13th 2016, categorised by test condition: O = Observation day, I = Test Condition I, II = Test Condition II.

Table 3: Overview of all mean results

Mean inflight and staying duration values	All	CC	EG	EM	J
O inflights	54	4	3	24	23
O staying duration	134	129	967	48	128
I inflights	35	1	3	10	21
I staying duration	116	32	977	28	34
II inflights	49	1	2	15	31
II staying duration	111	36	1122	35	74

Table 4: P-values of mean inflight comparisons between conditions. T-value = 2.23 in all cases. ∆ = Difference in inflights between means as a fraction of the original mean. [1]

Comparing daily inflights (n=6)	All	CC	EG	EM	J
O & I	0.10 ∆ = -0.35	**0.03** ∆ = -0.75	0.74 ∆ = 0.0	0.07 ∆ = -0.58	0.85 ∆ = -0.09
O & II	0.58 ∆ = -0.09	**0.03** ∆ = -0.75	0.73 ∆ = 0.0	0.24 ∆ = -0.42	0.47 ∆ = +0.39
I & II	0.15 ∆ = +0.4	1 ∆ = 0.0	0.63 ∆ = -0.33	0.45 ∆ = + 0.4	0.28 ∆ = +0.52

Table 5: P-values of mean individual stay duration comparisons between pooled conditions. ∆ = Difference in seconds between means as a fraction of the original mean. [1]

Comparing duration of stay	**All** n O = 322 n I = 223 n II = 296	**CC** n O = 25 n I = 6 n II = 6	**EG** n O = 16 n I = 20 n II = 14	**EM** n O = 145 n I = 62 n II = 88	**J** n O = 136 n I = 122 n II = 187
O & I	0.56 ∆ = -0.13 t = 1.96	**<0.00** ∆ = -0.76 t = 2.05	0.97 ∆ = +0.01 t = 2.03	**<0.00** ∆ = -0.40 t = 1.97	**<0.00** ∆ = -0.73 t = 1.97
O & II	0.30 ∆ = -0.16 t = 1.96	**<0.00** ∆ = -0.72 t = 2.05	0.56 ∆ = +0.16 t = 2.05	0.09 ∆ = –0.25 t = 1.97	<**0.00** ∆ = -0.42 t = 1.97
I & II	0.90 ∆ = -0.03 t = 1.96	0.79 ∆ = + 0.13 t = 2.23	0.65 ∆ = +0.15 t = 2.04	0.14 ∆ = +0.25 t = 1.98	**<0.00** ∆ = +1.18 t = 1.97

6.2 Data processing

Recorded footage was imported into a movie editing program (Adobe Premiere CS6). A digital timestamp was added to the footage. Zero point of the timestamp was matched with the moment the observer was done setting up and left for the observation position. The video was played. A bird entering within a two meter radius of the food resulted in a data entry in a spreadsheet program, in which species and corresponding timestamp would be specified. When the bird was seen leaving the perimeter its data entry would be extended with time of departure.

7. Results

7.1 First look at the data

Between May 21st and June 13th 2016, 18 tests were carried out, six of each test condition. The goal of consecutive testing was incidentally not met as a consequence of weather conditions or technical problems.

The setup attracted four species of birds: egyptian goose *(Alopochen aegyptiaca)*, carrion crow (*Corvus corone*), eurasian magpie (*Pica pica*) and jackdaw (*Corvus monedula*). The three upper graphs of figure 3 show the inflights for each species per day categorised by test condition. The three lower graphs of figure 3 show the cumulative duration of stay within the perimeter of each species per day, also categorised by test condition. Combined with table 3 they give an overview of both the activity (in terms of inflights) and prevalence of each species per day. Low activity, but high prevalence of the egyptian goose stands out in all conditions. An overall increase in jackdaw prevalence/activity, and decrease in eurasian magpie prevalence/activity over time is also noticeable.

7.2 Overall statistical procedure

Apple Numbers 2009 v2.3 and Microsoft Excel for Mac 2011 v.14.6.4 with a XLSTAT extension were used to analyse the data. The data was assessed to be normally distributed. Mean numbers of daily inflights were compared between test conditions using two tailed t-tests[1] (Table 4). Furthermore individual data entries were pooled for each test condition. Between the resulting data sets, mean visit durations were compared, also using two tailed t-tests (Table 5).

7.3 Food intake

In both the null condition and test condition II, all 80 grams of mealworms had been consumed by the end of every test. On the other hand, by the end of each test condition I session, there were still mealworms left (mean intake: 40.2 gram, sd: 9.4), excluding the test session on 11/6/2016, during which the entire container with mealworms was taken by a carrion crow.

8. Discussion

When interpreting these results it should be noted that we are dealing with very small numbers, so generalisations concerning the entire species should be avoided. Furthermore, it is important to consider that the number of inflights does not take individual birds into account. A constant number of inflights between two conditions, could easily mean that a smaller group of birds simply enters the perimeter more often.

8.1 Increasing and decreasing trends

The overall decrease of eurasian magpies and increase of jackdaws, during the course of the test period, has a number of possible explanations: increasing awareness over time, by the jackdaws, of the presence of the food, could explain their rising attendance. In the past, groups of jackdaws have been reported to work together to drive off eurasian magpies [49]. Furthermore, the end of May coincides with the end of the nesting period of eurasian magpies [50]. The numerous short visits eurasian magpies displayed during the beginning of the research period, might have had the goal of collecting food for their younglings. Consequently, young magpies no longer needing parental care, could be a factor affecting the parents observed foraging behaviour. Also, persistent presence of the Parrot AR.Drone may have had an increasingly repellent effect on the eurasian magpies. However, this last claim is pure speculation as this cannot be shown from the current dataset.

Since different test conditions were carried out alternatively these trends spread out equally over all test results and as such, influence all conditions equally.

8.2 Results for all birds

Treating all birds as one group, no conclusive results are found in either the comparison of mean duration of stay, or number of inflights between any of the conditions. This is not surprising, as the effects are cancelled out in the analysis when treating all the birds as one group. More fruitful analysis is possible when looking at the effects for specific species.

8.3 Carrion crow

In both conditions with the quadcopter present a significant decrease in the number of inflights of

[1] All t-tests in this study were two-tailed assuming unequal variances; statistical significance level was set to $p<0.05$ (boldface)

carrion crows was found. This decrease could mean two things:

1. Crows are staying longer within the perimeter in response to quadcopter activity which results in less in/out movement.
2. Crows are avoiding the perimeter in response to quadcopter activity.

Based on the mean staying time, which also significantly decreases, and the fact that most quadcopter days feature zero carrion crow inflights, this first claim can be rejected, indicating that crows are avoiding the area as a response to quadcopter activity.

Events during the test session on 11/6/2016 provide an interesting anecdote in light of this claim: a carrion crow picked up the container with mealworms, transported it to a location outside of the quadcopters flightpath and started consuming its contents on the newly appointed location. As carrion crows have increasingly been shown to posses far developed mental skills [51-53], this could be interpreted as an act of analysis and planning. Of course, this was just a single registration of a possibly coincidental event. Whether carrion crows develop tactics for preventing confrontation with UAV's, could be an interesting starting point for further research.

8.4 Egyptian goose

The observed geese seemed to be one and the same couple every time. They usually entered the perimeter as soon as the food was placed, foraged from the mixed seeds and left after about half an hour. From the quantitative data no significant effect on behaviour in either condition is found for them. However, they were often seen displaying clearly altered behaviour when confronted with the charging quadcopter (condition I): lowered head, pulled back wings and loud calls. The energy investment for fleeing being relatively high for geese [54], might play a role in not choosing a tactic of flight.

8.5 Eurasian magpie

Eurasian magpies stayed significantly shorter within the perimeter in response to the charging quadcopter. The magpies already displayed a tactic of relatively short visits when collecting the food in the null condition, making this result all the more significant. Results for condition II also lean towards a significantly shorter duration of stay and we hypothesis that more test will show this.

8.6 Jackdaw

In both condition I & II, jackdaws showed a significantly reduced visit duration. During condition I they were clearly seen leaving in response to the approaching quadcopter. In condition II it was less obvious why they chose to leave at a certain time, but apparently the presence of the quadcopter did cause them to adjust their style of foraging. The significant difference between visit durations of condition I & II quantifies this observed difference in response to instances of quadcopter presence.

Interesting to note is that the number of inflights, though not statistically significant, increased in conditions with a quadcopter present. This may indicate that the jackdaws embraced a tactic of more frequent, shorter visits.

8.7 Food consumption

The mealworms, in the container that was weighed at the end of each test session, were observed to be consumed by all species except the egyptian goose. Since condition I consistently showed about half of the food still being present by the end of the test sessions, it can be concluded that food intake was slowed down under the effects of the directly charging quadcopter. How different species were comparatively affected is not clear from the data.

9. Conclusion

The described setup has been was successful in testing the proposed hypothesis. Although being limited to testing for two disturbance indicators, within these boundaries useful data was collected. As hypothesised, species specific effects have indeed been shown. The influence of the UAV's flight style on the scale of the effect has been shown for jackdaws. More suspicions are suggested by the data and ask for further research.

Therefore, pursuing the goal of automating this setup in a scalable way is worthwhile. Consequent generation of larger data sets will aid in answering open questions such as: will habituation occur? How do characteristics such as noise level, size and design of different UAV's affect different species? How do different behaviours such as flight speed, altitude and tricks of UAV's affect different species?

9.1 Future considerations

A big limitation of the setup in its current form, is that it does not distinguish between individuals. The trend of ever improving consumer camera specs, combined with further advances in computer vision, provide a vision of the future in which this problem is overcome.

A way to expand upon this experiment with currently available technology would be to record audio during its runtime. This could be analysed for differences in sounds birds produce under different conditions. Also, putting a data recording measuring scale under the container with food, could offer a valuable extra dimension to the data.

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