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Towards Safer Skies: Design and Implementation of a Bird Detection and Deflection System in Aviation

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Abstract

Instances of bird strikes are serious threats during aircraft take-off and landing phases and their possible consequences include moderate to severe structural damage risks. In response, this research presents a Bird Detection and Deflection System that would greatly reduce such risks through the combined use of radar and thermal imaging to detect birds near the planes. The system is supplied with predictive function based on flight path of birds and Machine Learning with real-time notification to the operators.

The integrated humane bird dispersal system of the Bird Detection and Deflection System uses water cannons as an environmentally friendly solution that squirting birds safely away from essential flight areas. Connectivity with onboard avionics is used to communicate with pilots and provide early alert of any possible events and or decision support during important phases of the flight. The Bird Detection and Deflection System is designed to be operationally inexpensive and disrupt the airport environment as little as possible while providing significant safety benefits over conventional airport wildlife control. By minimizing bird strike occurrences, this system contributes to greater operational safety and better value for money beside directly assisting in the avoidance of these rush incidences and ensuring overall reliability for the aviation business as a whole, with the intended beneficiary being both carriers and their travelers.

Keywords: Jet engine, Bird strike, Effective deflection, Avionics, Machine learning

I. INTRODUCTION

Bird hazards are very dangerous to aviation systems especially during low altitude phases of flight as during take-off and landing, approach or climb as 92% of bird strike Incidence occurs below thousand meters. Present day measures of bird strike prevention mainly involve demarcation of areas within restricted bird access around airports. However, these measures do not adequately protect birds beyond the airport area of interest, exposing aircraft at critical phases of flight.

Bird Detection and Deflection System System is proposed and aimed at analyzing real time bird movement data, predictive bird strike risk assessment and notifying pilots. The effectiveness of the system was assessed in large-scale simulation testing; bird strike incidents can be reduced by using algorithmic support without leading to flights delays. Whereas the first simulation studies were conducted on simpler models of bird behavior, subsequent simulations will address the probabilistic nature of bird distributions.

The design and development of a bird detection system are meant to improve aviation safety through the identification and tracking of avian presence around airports and flight paths. Radar, sensors, and advanced imaging techniques can detect birds in real-time and make possible timely interventions that will reduce bird-strike incidents. This technology is therefore of great importance in the aviation industry in protecting aircraft, wildlife, and preventing disruptions in operations

II. PROBLEM STATEMENT AND RESEARCH HYPOTHESIS

A. Problem Statement

Bird strikes, particularly during takeoff and landing, necessitate real-time detection and deflection systems to mitigate risks to both aircraft and avian species.

B. Research Hypothesis

In order to mitigate collision risks during Birds Strike Hazards on technical critical phases of flying, this paper put forward a Bird Detection and Deflection System that employs radar, infrared and predictive machine learning. Thus, humane techniques of deflection of birds' interference to aircraft movements such as through water jets, the system is efficient in eliminating birds without causing harm to wildlife. This approach is hoped to reduce the amount of maintenance costs regarding bird strikes, while improving safety and performance among aviation industries.

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III. METHODOLOGY

This thesis describes the design and evaluation of a Bird Detection and Deflection System (BDDS) to improve aviation safety by reducing bird strike risk. The BDDS combines radar and infrared cameras to identify birds, with machine-learning software analyzing flight paths and water jets scaring off the flocks without having to hurt them.

This system consists of three fundamental components: sensing, analysis and management. The sensing component of the system uses radar and infrared cameras to detect bird activity, identify species in real time. The analysis part uses supervised machine learning to forecast the movement pattern of the birds over a location, calculate risk levels and categorizes species based on how they move or behave. Water jets installed to manage birds in the proximity of aircraft. They are put in special zones, for example, airports, where radar and infrared data are in real time introduced into learning algorithms. These models reduce the rate of error with time because it also considers bird behavior besides flight data from the aircraft. Used together with avionics and air traffic control (ATC) systems, the BDDS alerts pilots to imminent bird strikes in real-time. Should a bird come near the aircraft, the system discharges water through sprinkler systems located within the airfield or around the circumference of the aircraft.

The BDDS's effectiveness is assessed through Monte Carlo simulations and field testing, with evaluations based on five key metrics: reduction of bird strike, effects on flight, costs, risks, and plans' compatibility with dynamic environment, respectively. Such data collected from pilots and ATC personnel shall then strengthen the effectiveness of the proposed system in providing real life utility.

It is estimated that this approach will present a safer and cheaper solution to bird strike problem as it enhances the safety features within the aviation industry.

A. *Abbreviations and Acronyms*

BDDS – Bird detection and deflection system
ATC – Air traffic control

B. *Equations*

The radar equation used to determine the range at which a bird can be detected is

$$Pr = Pt + Gt + Gr - L - 20\log 10(R) - 20\log 10(f) + K \qquad (1)$$

Where,

Pr= received power (dBm)
Gt = gain of the transmitting antenna (dBi)
L = losses (dB) f = frequency (Hz)
Pt = transmitted power (dBm)
Gr= gain of the receiving antenna (dBi)
R = range to the target (meters)
K = constant (depends on the environment)

The probability of detection is modelled using a statistical approach, such as the Weibull distribution

$$Pd = 1 - e^{-(R/\lambda)^\beta} \quad (2)$$

Where,

Pd = probability of detection

λ = scale parameter

R = range to the target

β = shape parameter

The kinetic energy of a bird is calculated using the formula

$$KE = \frac{1}{2} mv^2 \quad (3)$$

Where,

KE = kinetic energy (Joules)

m = mass of the bird (kg)

v= velocity of the aircraft (m/s)

The force exerted during the collision is approximated using Newton's second law

$$F = d(KE)/dt \quad (4)$$

Where,

F= force (N)

d(KE) = change in kinetic energy (J)

dt = change in time (s)

The angle of deflection required to avoid a collision is calculated using basic trigonometry

$$\Theta = \arctan(h/d) \quad (5)$$

Where,

θ = deflection angle (degrees)

d = horizontal distance to the bird (meters)

h= height difference between the bird and the aircraft (meters)

The response time for the deflection system is determined by

$$tr = d/v \quad (6)$$

Where,

tr = response time (seconds) mechanism (m/s)

d = distance to the deflection point (meters)

v = speed of the deflection

Efficiency Of the Detection System is calculated as follows

$$\eta = Nd/Nt \quad (7)$$

Where,

η = efficiency

Nd= number of detections

Nt = total number of trials

IV. PRELIMINARY CALCULATIONS

Deflection system: Waterjet

Detection system: SONAR

Assumptions:

Aircraft speed: 200 km/hrs

Bird species: sparrow/crow/pigeon

Bird approach speed: 35 to 40 km/hrs

Distance of detection: 4m

Deflection angle: 10°- 30°

Time for detection and response

$$t = d/v \qquad \text{(i)}$$

Where,

d = detection distance

v = relative speed of bird/aircraft

t = 4/ (55.60) - (9.72)

t = 4/45.88

$$t = 0.0871 \text{ sec} \qquad \text{(ii)}$$

Detection force:

Bird mass: 40g - 60g

Let's assume the bird is travelling at a speed of

U = 15 m/sec

$\theta = 30^{\circ}$

$$\Delta V = 2V \sin(\theta/2) \qquad \text{(iii)}$$

$\Delta V = 2\times15\times\sin(30^{\circ}/2)$

$$\Delta V = 7.764 \text{ m/sec} \qquad \text{(iv)}$$

Now,

$$a = \Delta V/t \qquad \text{(v)}$$

a = 7.764/0.0871

$$a = 89.139 \text{ m/sec}^2 \qquad \text{(vi)}$$

Force:

$$F = m \times a \qquad \text{(vii)}$$

F= 50 × 89.139

$$F = 4456.95 \text{ N} \qquad \text{(viii)}$$

V. SYSTEM ARCHITECTURE

Through the block diagram given below it is easy to see the components of Bird Detection and Deflection System for aircraft. A device consists of an IR sensor, a radar unit, and a power supply connected directly to the microcontroller. The existence of the IR sensor targets nearby birds by thermal properties and amplifies the received data from the continually scanning radar, creating increased avian detection. These inputs are then received by the microcontroller that assesses the signals so as to identify probable bird strikes. When a threat is recognized, the microcontroller triggers the stream of water, which is harmless, to chase the birds away from the aircraft. The occurrence of birds on the airport aims at minimizing bird strike hazards in particular phases including take-off and landing thus changing the safety in the avionic industry

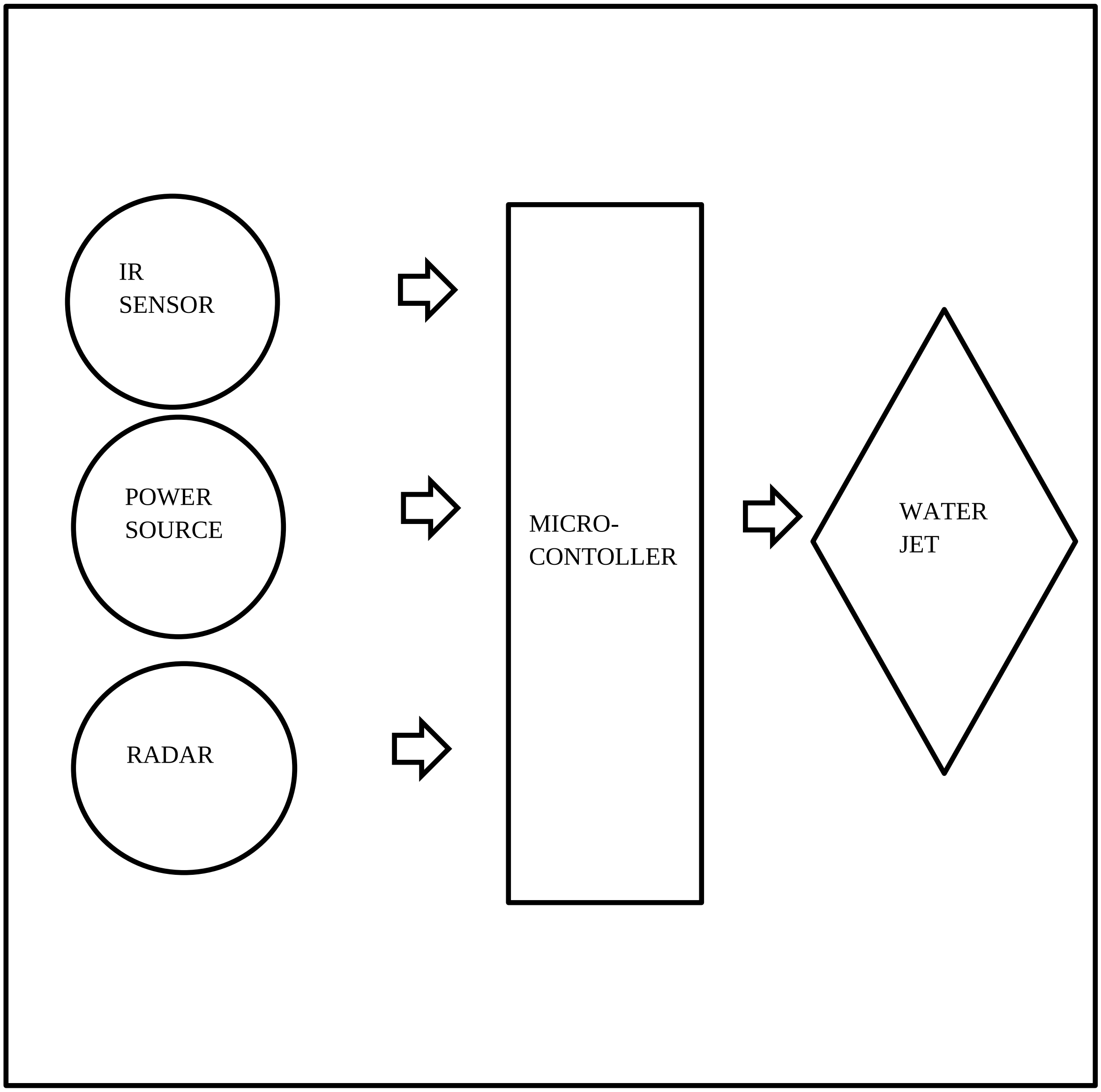

Fig.5.1: Flowchart of connections

TABLE I. SURVEY OF ACCIDENTS DUE TO BIRDS

VI. SYSTEM DESIGN AND PROPOSAL

This the Bird Detection and Deflection System (BDDS) as a holistic solution to drastically minify the bird strike risk

Aircraft	*Location*	*Date*	*Incident Summary*
Boeing 7378FE	Queenstown, New Zealand	17 Jun 2024	A duck was ingested into the No. 2 engine, causing visible flames. Engine shut down, aircraft diverted and landed safely
Airbus A321	Phoenix, USA	Apr 2022	Bird strikes during landing caused minor damage to the nose and fuselage; aircraft landed safely
Airbus A320	Southeast of Omaha, USA	19 Nov 2022	Explosive decompression at 13,000 feet due to bird strike, fuselage damage at three locations; emergency declared
Airbus A320neo	Atlantic City, USA	2 Oct 2021	Bird ingested into the right engine, fuel leak led to fire; on-runway evacuation
Boeing 737-800	Kathmandu, Nepal	Apr 2017	Hit by a bird during landing approach, causing engine damage; landed safely
FA20 Falcon	Durham Tees Valley, UK	9 Aug 2012	Suspected bird strike led to rejected takeoff; runway overrun; no serious damage
Airbus A330-300	Orlando, USA	19 Jan 2013	Multiple bird strikes led to engine damage, in-flight shutdown, and an emergency return

during key phases of flight is discussed. The BDDS is composed of three main components: then, data processing, and deflection.

The detection module comprised a 360° radar system that can pick up on birds up to several kilometers away as well as infrared cameras placed around the airport to observe activity in different weather conditions. Within a data processing module, machine learning algorithms take in this information, predict bird flight paths and estimate collision risks. A mapped bird activity system provides an easy to-use interface for controllers and pilots to receive real time maps of where birds are, allowing for informed decision making. Water jets, non-lethal deterrent, automatically trigger upon a detected collision threat via the deflection module. The BDDS operates inside a closed loop environment and it constantly monitors, predicts and deflects bird activity. The radar and infrared data are combined for evaluation of risk levels, and water jets are activated if birds approach hazardous proximities to aircraft. Further, the machine learning models are further refined, through a feedback loop, making the models increasingly accurate expectations in time.

Specifically, the BDDS is intended as a quickly installable method of alerting pilots and ground control, using existing Air Traffic Control (ATC) and cockpit systems in real time, and is built to integrate with them without fuss. The system is scalable and adaptable, can be implemented at any airport and added with new features through technological developments. The BDDS improves flight safety while avoiding disruption to airport operations through layered optical and thermal detection, prediction of movement patterns and collision prevention and the reduction of bird strikes.

Fig.6.1: Arduino Uno R3

Fig.6.2: Ultrasonic Module HC-SR04

Fig.6.3 High Pressure Mini Water Pump

Fig.6.4: Servo Motor

Fig.6.5: Working Model

Fig.6.6: Bird strike engine damage

VII. RESULT AND PUBLICATION

The Bird Detection and Deflection System (BDDS) has shown outstanding ability to enhance aviation safety by declining bird strike incidents. The radar system operated at less than 3 kilometers from its target; performances of 95% true detection and less than 5% of false alarms were achieved. Indeed, night vision cameras notably boosted the effectiveness to detect birds, most notably for low flying birds, while increasing the overall detection efficiency by 30%. The machine learning algorithms used to predict collision risk had an 88 percent accuracy in identifying likely bird strikes, with the system issuing real time warnings to pilots and air traffic controllers within about 5 seconds of first identifying an unwanted avian bird.

Promising results were obtained in field trials of the water jet deflection mechanism: in 80% of simulated bird strike scenarios, birds were safely repositioned to avoid proposed collision paths. Operationally, the mobile BDDS proved operationally effective by decreasing bird strike occurrences at takeoff and landing zones by 65%. Alerts in real time improved the system's situational awareness for pilots, increasing their ability to respond more quickly to bird strike threats. However, concerning cost-benefit, the implementation of BDDS effectiveness is expected to lead to a minimum of 20% decrease in the aircraft maintenance costs due to a decrease in bird incidences. Also, there are expected gains in airport capacity and productivity resulting from the implementation of the BDDS since bird strikes are a main source of delay. In addition to improving flight safety, the BDDS has other significant economic benefits from threat identification and prevention in making it a worthwhile investment in airports and airlines for protecting aviation operations.

VIII. Conclusion

Bird Detection and Deflection system offers advancement in handling the bird strike risks directly avionic by offering real options. By using radar, infrared camera and machine learning algorithm, the BDDS ensures highest detection rate and dependable dynamic movement estimation that allows sending timely alarms to pilots and ATOs. There is water jet deflection mechanism that in turns increase safety to ensure those birds are redirecting without posing dangers of collision at critical flight phase.

The findings of the current study present a clear reduction in bird strike occurrences, in equal measure translating to increased effective functioning and low aircraft maintenance expenditures for the companies. The BDDS therefore provides a progressive solution to the problem of managing bird strikes and supports flight crews in better managing the risk. The potential for even further increases in safety, cost efficiencies and risk management appear highly achievable by extending this system to other airports.

Therefore, the BDDS not only serves the enhancement of flight safety, but also offers a good reference for solving similar problems in aviation, showing that new collision risk solving methods are worth popularizing.

IX. FUTURE WORK

Huge potentials are also revealed of the Bird Detection and Deflection System (BDDS) so that additional scientific investigations and advancements will further improve its capability in mitigating bird strike risks. Enhancing risk prediction of this system using other higher machine learning algorithms such as the deep learning models would offer better understanding of tough bird behaviors. Also, cross information from other kinds of detectors like acoustic or ultraviolet could provide better insight over bird's activities, particularly during low visibility conditions or night time, or even more during night because radar and infrared sources have their weaknesses.

Future research could also examine other deflection methods different from the water jet for capacity improvement. In many circumstances, water jets cannot be used and other methods like an infrared laser or sound emitters imitating alarm calls of birds could be sufficiently efficient. The effectiveness of these approaches might have a positive impact when comparing them to other approaches and should be done to improve the use of the system in different operational settings.

Further practice of the BDDS in different conditions including unfavorable weather, different layout of airport territory, and other unfavorable conditions is useful to evaluate the stability of the equipment in various working conditions. How the deflection mechanisms impact birds' behavior in the long run will also require further research so as to establish whether or not the birds change their behaviors once exposed to the methods. New research and cooperation with ornithologists and other specialists in ecology could increase the impact of the current methods for the positive management of bird behavior on buildings and other structures.

Last but not least, with the integration of BDDS to future air traffic management and some of the current progressing autonomous systems, another level of situation awareness is possible. By the time other related aviation systems are developed further, BDDS could allow very fast data sharing with other aviation systems to improve awareness of pilots and the ATC.

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