A Final Report to Offer Engineering Solutions to Reduce the Urban Area Wild Boar Population Near Hekimköy Complex, Türkbükü, Bodrum



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# Abstract

In Hekimköy Complex, Türkbükü, Bodrum, simultaneous accommodation of site residents and wild boars creates an unsafe environment for outdoor activities. In the pilot study area, wild boars pollute the environment, cause traffic accidents, carry diseases, attack people, and damage public infrastructure. The aim of this project is to reduce the urban area wild boar population near Hekimköy Complex by offering three engineering solutions: Kinect-based deterrent system with an odor repellent, machine learning-based acoustic deterrent system, and sensor and artificial intelligence-based visual deterrent system. Each solution is assessed against feasibility, monetary cost, and environmental safety impact criteria using a literature review, market research, and field observation methodology. The Kinect-based deterrent system with an odor repellant is energy-efficient and considerate of the environment, but its ongoing expenses and potential for odor problems make it less desirable. The machine learning-based acoustic deterrence system is advanced yet expensive and unproven. On the other hand, the sensor and artificial intelligence-based visual deterrent system balance cost-effectiveness, community acceptability, and long-term operation, yet its setup necessitates advanced technical knowledge. After all things considered, the recommended solution is the sensor and artificial intelligence-based visual deterrent system. The suggested action plan involves the purchase of the system’s components, installation of the systems by HC electricians and a software engineer, field testing, and operational deployment of the systems. Also, it is recommended that Hekimköy Complex establish a regular maintenance plan and document scenarios where the systems fail to detect and deter wild boars for sustainability and operational improvements.

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# 1.0 Introduction

The nature of the interaction between humans and wildlife has changed, particularly in urban and suburban environments [1]. An example of this shift is the increase in urban area wild boar population [2]. In Hekimköy Complex (HC), Türkbükü, Bodrum, the rapid spread of wild boars into human-populated areas has created an alarming situation because the simultaneous accommodation of wild boars and humans in the same environment poses severe threats to human safety and property [3], [4]. Wild boars are responsible for some of the traffic accidents that result in the death of the driver or themselves many times at night on dark roads that pass through HC, cause pollution by knocking over garbage bins [5], carry diseases [6], and attack and injure HC residents.

The offered project aims to reduce wild boar population within HC with three engineering solutions. Its impact is to implement wild boar deterring systems throughout the HC upon detecting wild boar presence to add extra security layer for HC residents against wild boar presence. The project’s significance lies in its potential to generate solutions that can be adapted to all regions facing similar disturbances caused by wildlife, regardless of the type of animal species.

# 2.0 Problem Definition

Beyond the potential for traffic accidents in the HC, the pilot study area (PSA), wild boars are responsible for damage to public infrastructure, parks, and private gardens [7] in HC. HC residents are irritated by the boars’ raids of trash cans because of the resulting pollution in HC. Moreover, wild boars can transmit diseases to HC residents and their pets [8] and even pose a physical threat to them [4]. Therefore, wild boars create an unsafe environment for outdoor activities within HC [9].

## 2.1 Root Causes

Three root causes of HC’s problem are easy access to food and water [10], insufficient hunting pressure [11], and expanding urbanization into forested areas occupied by wild boars [12].

### 2.1.1 Easy Access to Food and Water

Urban areas' abundant food and water sources strongly attract wild boars [10]. These readily available resources are often found as food waste in HC trash bins, fruits and vegetables grown in private gardens of HC residents, and water bodies.

### 2.1.2 Insufficient Hunting Pressure

Wild boars are attracted to urban areas due to the absence of hunting pressure in their natural habitats [11]. As a result, they overpopulate, leading them to seek food and shelter in urban environments where these resources are more readily available.

### 2.1.3 Expanding Urbanization into Forested Areas Occupied by Wild Boars

Urban expansion into forested areas, previously occupied by wild boars, draws these animals into urban environments as it disrupts their natural habitat [12].

## 2.2 Problem Scope

* Who HC residents
* What: Wild boar intrusion into urban areas through HC
* When: The problem persists year-round but worsens in summer due to the increased HC population from holiday migrations [13].
* Where: HC, Türkbükü, Bodrum
* Why: Increase in wild boar and human interactions leads to conflicts.
* How: Wild boars cause car accidents and physical harm to people, carry diseases, damage properties, and create pollution [7].

# 3.0 Proposed Solutions

Three engineering solutions to the problem mentioned in HC are a Kinect-based deterrent system with an odor repellent, a machine learning-based acoustic deterrent system, and a sensor and artificial intelligence-based visual deterrent system. For all systems, HC electricians will physically install 28 systems on strategically chosen streetlight poles to leverage from their height for optimal camera views and as a power source for the systems near four main garbage collection areas and eight bushlands [13] in HC. A software engineer will also be involved in software setup in the control unit.

## 3.1 Kinect-Based Deterrent System with an Odor Repellent

The introduced system consists of three pieces of hardware internally connected with various signals: a Kinect camera, a control unit [14], and an odor dispenser. The Kinect camera device, known as the "Kinect for Xbox," incorporates several sensors (see Appendix A, Figure 1, and Table 2) to create a 3D depth map of its surroundings [15] to track the movements of objects [16]. The system’s purpose is to send activating signals through the control unit to the odor-repellant dispenser to drive wild boars away after detecting their presence with the help of a Kinect camera.

The system will work in three phases. The distance information between the camera and the object will be obtained using Kinect's infrared projection in the image acquisition phase. Then, this information will be used to create a depth image of the object (see Appendix A, Figure 2) [14]. The detection phase will begin with a Binary Large Object (BLOB) analysis, which is helpful for object detection tasks [17], [18], of the shape and size of objects using the depth image (see Appendix A, Figure 3). An extra layer of motion detection by utilizing the optical flow method, which can be mathematically represented (see Appendix A, Figure 4) [14], will be applied to the extracted blobs within the depth image because there can be misidentifications due to the resemblance of animals to rocks or trees.

The odor-repellent secretion phase will begin if the captured animal is identified as a wild boar [19], [20]. A programmable logic controller will receive the incoming signal by a wired communication protocol, utilizing general-purpose input-output pins, and interpret it. Then, it will communicate with the odor-repellent dispenser to trigger the release [21]. The odor-repellent ‘‘Wildschwein-StoppÒ’’ will be filled into the scent dispensers. It claims to mainly deter wild boars by an offensive smell that should reflect a mixture of several predator odors [22].

## 3.2. Machine Learning-Based Acoustic Deterrent System

An acoustic deterrent is being offered by combining an infrared night vision camera [23] that can detect movements of wild boars in low visibility, along with several machine learning algorithms [24] and an ultrasonic frequency generator (see Appendix B, Figure 5).

The Raspberry Pi 3B (Rpi), a microcontroller that will serve as the overall module brain [25], will receive the video straight from the camera that will record surroundings continually. The Rpi will capture frames at a frame rate of one frame per five seconds. Then, the Python OpenCV [26] library, a computer vision library used for image processing tasks, will process the frames [27]. Processed frames will be used to forecast if any wild boars are present in the vicinity.

A machine learning model built on the Convolutional Neural Network (CNN) architecture will be used to make the prediction [28]. As a deep-learning technique for image recognition, CNNs extract simple image patterns, combine them to recognize complex features, and reduce dimensionality for efficient computation [29]. The machine learning model will be trained using a dataset of wild boar images [28]. According to the prediction about the existence of wild boar, the Rpi will send a signal to the ultrasonic frequency generator, which has an audible range of 10-15 meters with a span of 110 degrees. The ultrasonic repellent will produce frequencies ranging from 15 to 65 kHz, which wild boars can hear and be disturbed by, but humans cannot [30]. Based on the sizes of all hardware components, 30 cm x 20 cm x 20 cm stainless steel outer casings will be designed to hold and protect the hardware (see Appendix B, Figure 6).

## 3.3 Sensor and Artificial Intelligence-Based Visual Deterrent System

Passive Infrared Motion (PIR) Sensors will be configured over streetlights to sense the movement of any surrounding objects. Motion detection will then cause the camera to record live streaming and store it on Rpi [31]. Rpi is a single-board computer that can store media files on its storage device [25]. After the video is captured, a wild boar detection model will try to detect if the sensed object is a wild boar using videos captured by the camera. After the model has finished running, if any wild boars are detected, the light-emitting diode (LED) light strips will turn on to divert them away (see Appendix C, Figures 7 and 8).

PIR sensors use variations in infrared radiation to identify motion [31] to detect heat from warmer objects than absolute zero [32]. Therefore, they will identify and report motion when a large, warm object like a wild boar enters their field of vision. This report activates a camera connected to the Rpi module to start recording live and storing the video on Rpi.

After all, the detection phase in the offered system relies on the YOLO V3 algorithm (see Appendix B, Figure 9), which is renowned for its effectiveness in identifying animal species within video streams [33]. YOLO V3, or "You Only Look Once," operates on the principle of regression, enabling it to predict the classes of detected objects and their corresponding bounding boxes within a single algorithm pass, ensuring identification without extensive comparisons [34], [35]. The Rpi module will be connected to the LED light strips. Upon confirmation of a wild boar intrusion, LED light strips will start blinking with irregular repetitions to annoy and guide wild boars out of HC.

# 4.0 Criteria for Assessing Solutions

Criteria for assessing solutions are feasibility [36], monetary cost [37], and environmental safety impact [38]. Feasibility and monetary cost, both crucial at 35% weight, gauge a solution's practicality and economic fit within HC's budget. Environmental safety, weighted at 30%, ensures solutions are eco-friendly. All criteria are essential for a solution's successful integration and long-term use in HC.

## 4.1 Feasibility

The applicability of the three systems in the three offered solutions was assessed by verifying the systems’ operational functionality [14], [24], [25], [31], [32]. Practicality assessment of all solutions involved evaluating each system's construction time and labor requirements [20], [26], [33]. The first and third solutions’ acceptability was determined based on the suitability of visual and odor-deterrent installation locations to avoid disturbing HC residents [39].

## 4.2 Monetary Cost

The cost to purchase the necessary hardware and software and continuing sustainability were examined [19], [28], [40]. The monetary cost criterion also assessed the use of available funds at HC [41]. Components’ costs, which include both purchase and delivery costs, labor costs, and ongoing operational expenses post-implementation, were checked for each solution (see Appendix D, Table 8 for the table that shows what cost categories will be checked for each solution).

## 4.3 Environmental Safety Impact

Whether the three deterrents that were used in implementing all the offered systems, odor-repellent [22], [23], ultrasonic frequency [30], [42], and LED light [43], will harm the ecological balance in HC by causing other animals to leave their natural habitats were evaluated.

# 5.0 Research Methodology

The researched methodology to check the solutions against each criteria set consists of literature review [44], [45], market research [46], field observation [47].

## 5.1 Literature Review

The literature review was used to assess all three of the offered systems' feasibilities [14], overall monetary costs [48], and environmental safety impacts [23], [30], [43], [49].

## 5.2 Market Research

Market research was utilized against the monetary cost criterion to reach the product, delivery, labor, and post-implementation costs of all solutions [40], [41], [50].

## 5.3 Field Observation

Field observations in HC were used across all offered solutions to assess the acceptability of the offered deployment sites, specify material choices based on weather conditions, and evaluate the environmental impacts of the systems’ deterrents on HC species.

# 6.0 Results and Analysis

Kinect-based deterrent system with an odor-repellent, machine learning-based acoustic deterrent system, and sensor and artificial intelligence-based visual deterrent system were assessed against feasibility, monetary cost, and environmental safety impact criteria using the described research methodology. The weighs for feasibility, monetary cost, and environmental safety impact criteria are %35, %35, and %30, respectively. Feasibility and monetary cost are key criteria, which reflect if a solution fits within the HC's practical, social, and budgetary constraints. Environmental safety impact criterion ensures that solutions preserve HC’s natural balance and support sustainability.

All solutions have received points for each criterion, and their total points have been calculated with respect to the weight distribution by multiplying the collected scores with relative normalization factors (see Appendix D, Table 3).

## 6.1 Feasibility Analysis

A four-indicator checklist was developed to analyze each solution for the feasibility criterion (see Appendix D, Table 4). This checklist investigates the solutions’ acceptability, applicability, and practicality in HC.

### 6.1.1 Kinect-Based Deterrent System with an Odor-Repellent’s Feasibility

The Kinect-based deterrent system requires minor installation adjustments [17] and appears to be compatible with existing infrastructure. It is almost certain that the Kinect camera is an available and mature technology [18] poised for application, and BLOB analysis is a reliable object detection method [17], [18], contributing to the solution's applicability. However, potential odor concerns [21] that may arise due to the use of odor repellent could raise concerns among the community, potentially necessitating outreach for acceptance [22]. The installation's complexity demands specialized skills [14], yet it appears within manageable limits for trained personnel [15]. The monthly need to refill the odor repellent in the Kinect-based system adds a maintenance task [22], which may affect its practicality. Kinect-based deterrent system with an odor-repellent collects 5/10 points for feasibility (see Appendix D, Table 5).

### 6.1.2 Machine Learning-Based Acoustic Deterrent System’s Feasibility

The machine learning-based acoustic deterrent system seems compatible with existing streetlight installations [23] among HC. This provides a practical aspect that could smooth its adoption. Although the machine learning model built on CNNs appears to be advanced and available [24], its application for wild boar detection is novel and unproven. This innovative feature contributes to the system's uniqueness but also is anticipated to substantially lower its applicability rate. It can be tentatively concluded that the system has a non-invasive nature that makes it agreeable to the community [30]. However, its technical complexity [28], involving sophisticated elements like machine learning and computer vision, likely calls for specialized skills [25], [26], [28] in setup. Machine learning-based acoustic deterrent system gathers 6/10 points for feasibility (see Appendix D, Table 6).

### 6.1.3 Sensor and Artificial Intelligence-Based Visual Deterrent System’s Feasibility

The sensor and artificial intelligence-based visual deterrent system, designed for streetlight installation, seems to require minimal modification of existing infrastructure for integration [25]. Mature technologies like PIR sensors [31] and Rpi [22] underpin the system, and the YOLO V3, which appears to be a proven artificial intelligence model [31], is almost certain to add a robust detection layer. This system is likely to have a high acceptance rate because the system is discreet and non-disruptive to the HC residents. The initial setup demands sensor calibration [32] and artificial intelligence configuration [33], which need strong technical expertise [34], [35]. Sensor and artificial intelligence-based visual deterrent system accumulates 7/10 points for feasibility (see Appendix D, Table 7).

## 6.2 Monetary Cost Analysis

To assess each solution against the monetary cost criterion, the solutions’ total implementation costs, which include the acquisition, delivery, labor, and ongoing operational expenses, are estimated. Given that some components require purchase from abroad, all costs are converted to TRY before probing, using the exchange rates on 5 December 2023 (£1 = 31.33 ₺, $1 = 28.92 ₺) [51]. A three-indicator checklist was constructed to evaluate these costs by checking their compatibility with the predicted budget (see Appendix D, Table 8). The analysis excludes future repair costs and software engineer fees due to their unpredictability and the broad range of potential expenses involved with high-level algorithm setup and software installation.

For all systems, installation, which demands half a day's work per system, is reasonably priced at 4,900 ₺, considering the part-time contributions of 28 HC electricians, each with a daily wage of 350 ₺, for the systems’ setup, reflects a moderate cost within the allocated labor budget.

The budget that HC’s stakeholders can allocate for purchasing and installing the solutions across HC totals 210,000 ₺. Additionally, a monthly budget of 15,000 ₺ is estimated to be allocated for the ongoing operational expenses of these systems.

### 6.2.1 Kinect-Based Deterrent System with an Odor-Repellent’s Monetary Cost

Market research was conducted to determine the prices of each required component to estimate the total monetary cost of one system’s products in TRY (see Appendix D, Table 9 for product costs). Acquisition expenses seem to amount to 178,662.96 ₺ for 28 such systems [52], [53], [54], which requires a substantial portion of the allocated budget for implementation. Ongoing operational expenses of 28 systems for the odor repellent's monthly renewal [22] are estimated at 31,531 ₺ [55], which exceeds the 15,000 ₺ budget estimated for the post-implementation costs and drastically increases the overall implementation cost. As a result, Kinect-based deterrent system with an odor-repellent collects 3/8 points for the monetary cost criterion (see Appendix D, Table 10).

### 6.2.2 Machine Learning-Based Acoustic Deterrent System’s Monetary Cost

The cost of each component necessary for implementation is investigated, as the total cost to build a single system is calculated to assess the overall monetary cost of the system’s products (9,448.04 ₺) [56], [57], [58], [59], [60] against the allocated budget (see Appendix D, Table 11 for products’ costs). The total expenditure for 28 units appears to amount to 264,545.12 ₺. This figure significantly exceeds the budget’s scope. Notably, this system requires almost zero ongoing costs, which enhances its cost-effectiveness. These financials give the machine learning-based acoustic deterrent system 4/8 points for the monetary cost criterion (see Appendix D, Table 12).

### 6.2.3 Sensor and Artificial Intelligence-Based Visual Deterrent System’s Monetary Cost

The prices of each required product for the system were examined to estimate the total cost for a single setup (4,196.49 ₺) [56], [57], [61], [62], which helps to gauge how the full expense aligns with the designated budget (see Appendix D, Table 13). The combined cost for the necessary components is 117,501.72 ₺ for 28 systems, which echoes a moderate amount within the budget. A significant advantage of this system is the absence of recurrent expenses after installation, which underscores its long-term financial viability within the allocated budget. The sensor and artificial intelligence-based visual deterrent system gathers 6/8 for the monetary cost criterion (see Appendix D, Table 14).

## 6.3 Environmental Safety Impact Analysis

A two-indicator checklist was devised to appraise each solution against the environmental safety impact criterion (see Appendix D, Table 15). This checklist examines the solutions’ effect on local flora, fauna, and ecological balance, and the extent of sustainable material use and resource efficiency.

### 6.3.1 Kinect-Based Deterrent System with an Odor-Repellent’s Environmental Safety Impact

The Kinect-based deterrent system with an odor-repellent uses odor repellent ‘‘Wildschwein-StoppÒ’’ [22], which may temporarily disturb local wildlife and flora [19]. However, it is not expected to impact the ecosystem balance long-term [20]. Electronic devices that will be used in this system, such as the Kinect camera [18] and the control unit [14], do not typically require frequent replacement and have low energy consumption [63], which contributes to the system’s sustainability. As a result, the Kinect-based deterrent system gathers 3/5 environmental safety impact points (see Appendix D, Table 16).

### 6.3.2 Machine Learning-Based Acoustic Deterrent System’s Environmental Safety Impact

Ultrasonic frequency range (15 to 65 kHz) that will be used in the machine learning-based acoustic deterrent systems targets wild boars [30] likely without affecting other wildlife or the ecosystem [24], as they are not known to impact flora, too [29]. Rpi and other electronics appear to be energy-efficient, though not fully sustainable [21]. The use of a machine learning model for detection reduces resource efficiency [64] by causing activation even when unnecessary [25]. The machine learning-based acoustic deterrent system accumulates 3/5 points against the environmental safety impact criterion (see Appendix D, Table 17).

### 6.3.3 Sensor and Artificial Intelligence-Based Visual Deterrent System’s Environmental Safety Impact

PIR sensors, LED lights, Rpis, and Rpi cameras seem to be non-intrusive to flora and selectively target wild boars, minimizing the impact on non-target wildlife and the ecosystem [31]. The Rpi, Rpi camera [21], and PIR sensors are relatively low-energy-consuming devices, and LEDs are energy-efficient [65]. The system operates only upon detection, conserving energy and minimizing unnecessary usage [31]. This could be interpreted as evidence of more enhanced sustainability of the system. The sensor and artificial intelligence-based visual deterrent system scored 4/5 on the environmental safety impact scale (see Appendix D, Table 18).

# 7.0 Conclusion and Recommendations

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Solutions | Feasibility  (%35) | Monetary Cost  (%35) | Environmental Safety Impact  (%30) | Total Scores |
| Kinect-Based Deterrent System with an Odor-Repellent | 17.5 | 13.14 | 18 | 48.64 |
| Machine Learning-Based Acoustic Deterrent System | 21 | 17.52 | 18 | 56.52 |
| Sensor and Artificial Intelligence-Based Visual Deterrent System | 24.5 | 26.28 | 24 | 74.78 |

The solutions’ final assessment scores against every criterion are presented in Table 1.

Table 1: Solutions’ Total Scores

The Kinect-based system is rejected due to its high post-implementation costs and estimated lower acceptability rate, which can arise from potential odor concerns, although it is environmentally considerate and low on energy consumption. The machine learning-based system, although energy-efficient, is also rejected due to budget overrun and unproven technology. On the other hand, the sensor and artificial intelligence-based system is the recommended solution. Despite the need for strong installation expertise, it is the most cost-effective and environmentally safe. It also has the highest feasibility rate.

The recommended action plan for the implementation is as follows (see Appendix E, Figure 10 for the action plan flowchart):

1. PIR sensors, Rpi units, cameras, and LED light strips should be acquired.
2. A software engineer should configure the YOLO V3 algorithm on the Rpis, and simultaneously, HC electricians should install PIR sensors and cameras on selected streetlights.
3. HC electricians should connect Rpis to cameras and ensure communication between PIR sensors and cameras.
4. HC electricians and the software engineer should test completed setups for functionality and detection accuracy and document procedures for scenarios where the system fails to detect wild boars.
5. LED light strips should be connected to the Rpis to activate wild boar deterrence upon detection by HC electricians.
6. A regular maintenance schedule should be established.

# 8.0 Appendices

## Appendix A – Kinect-Based Deterrent System with an Odor Repellent

Figure 1: Kinect Construction [16]

Table 2: Kinect Specifications [16]

Figure 3: Circumscribed Rectangle Adjustment Procedure [16]

Figure 2: Depth Image Using Infrared Radiation Example [16]

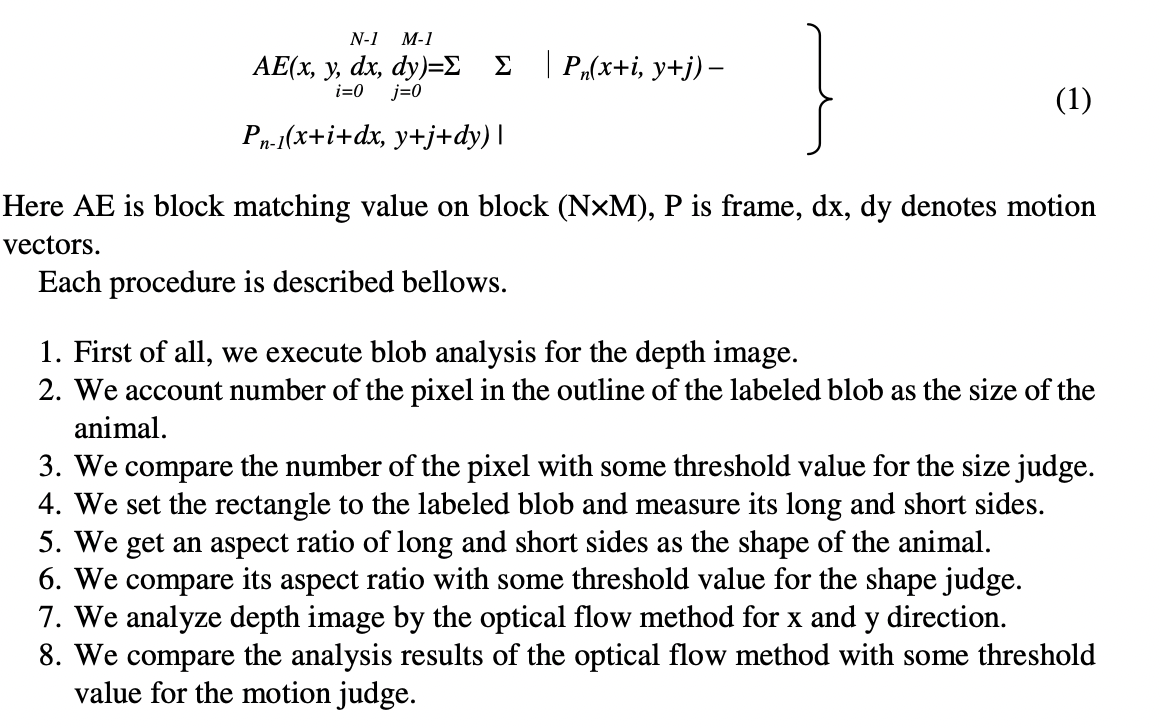


Figure 4: Optical Flow Method Mathematical Description (Here, AE is the block matching value on the block (N×M), P is the frame, and dx and dy denote motion vectors.) [16]

## Appendix B – Machine Learning-Based Acoustic Deterrent System

Figure 5: Solution Network Diagram [24]

## Appendix C – Sensor and Artificial Intelligence-Based Visual Deterrent System

Figure 6: Designed Animal Repellent System Outer Casing [24]

Figure 9: YOLO V3 Network Architecture [31]

LED LIGHTS

Figure 8: System Flow Chart [31]

LED LIGHTS

Figure 7: System Architecture Block Diagram [31]

## Appendix D – The Criteria’s Checklists

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Criteria | Indicator Count | Attainable Scores | Weight and Normalization Factors | Weighted and Normalized Scores |
| Feasibility | 4 | 10 | 3.50 | [0-35] |
| Monetary Cost | 3 | 8 | 4.38 | [0-35] |
| Environmental Safety Impact | 2 | 5 | 6.00 | [0-30] |

Table 3: Score and Indicator Distribution per Criterion

|  |  |  |
| --- | --- | --- |
| Indicators | Score Interval | Comments |
| Integration into Existing Infrastructure | [0-3] | (0) Complete overhaul required  (1) Major modifications needed  (2) Minor modifications sufficient  (3) No modifications needed |
| Technology or Method Availability and Maturity | [0-2] | (0) Technology/method undeveloped or experimental  (1) Technology/method available, limited testing  (2) Technology/method widely available, proven effective |
| HC Community Acceptance | [0-2] | (0) Strong opposition, significant acceptance barriers  (1) Some resistance, requires persuasion  (2) Accepted with support, minimal concerns |
| Technical Implementation | [0-3] | (0) Extremely complex, specialized skills required  (1) Considerable complexity and external expertise needed  (2) Manageable complexity with existing resources  (3) Straightforward, easily managed |
| Possible Total Point | 10 | |

Table 4: Feasibility Criterion Checklist

|  |  |  |
| --- | --- | --- |
| Indicators | Scores | Comments |
| Integration into Existing Infrastructure | 2 | Minor installation adjustments are needed [17]; the infrastructure is largely compatible |
| Technology or Method Availability and Maturity | 2 | * Kinect is a mature, tested technology ready for application [18]. * BLOB analysis is a successful object detection algorithm [17], [18]. |
| HC Community Acceptance | 1 | Potential odor concerns [21], may require community persuasion [22] |
| Technical Implementation | 0 | * Installation complex [14]; requires specialized skills but manageable [15]. * Requires monthly renewal of the odor repellent [22] |
| Total Point | 5/10 | |

Table 5: Feasibility Criterion Checklist for Kinect-Based Deterrent System with an Odor-Repellent

|  |  |  |
| --- | --- | --- |
| Indicators | Scores | Comments |
| Integration into Existing Infrastructure | 2 | Requires some installation on streetlights; relatively compatible [23] |
| Technology or Method Availability and Maturity | 1 | Machine learning is advanced [24], but the application for wild boars is novel. |
| HC Community Acceptance | 2 | Likely accepted; non-invasive and no odor issues [30] |
| Technical Implementation | 1 | Complex setup with machine learning and computer vision [28]; specialized skills required [25], [26], [28] |
| Total Point | 6/10 | |

Table 6: Feasibility Criterion Checklist for Machine Learning-Based Acoustic Deterrent System

|  |  |  |
| --- | --- | --- |
| Indicators | Scores | Comments |
| Integration into Existing Infrastructure | 2 | Installation on streetlights needed; minor integration effort [25] |
| Technology or Method Availability and Maturity | 2 | PIR sensors [31] and Rpi [22] are mature; YOLO V3 is a proven AI model [31]. |
| HC Community Acceptance | 2 | High acceptance is likely. The system is discreet and non-disruptive to the HC residents. |
| Technical Implementation | 1 | It requires the setup of an AI model [33] and sensor calibration [32]. Technical expertise is needed [34], [35]. |
| Total Point | 7/10 | |

Table 7: Feasibility Criterion Checklist for Sensor and Artificial Intelligence-Based Visual Deterrent System

|  |  |  |  |
| --- | --- | --- | --- |
| Indicators | Budget  (Annual monetary expense is %5 of annual dues income.) | Score Interval | Comments |
| Product Costs | 200000 ₺ | [0-3] | (0) Exceeds budget significantly  (1) Requires a substantial portion of the budget  (2) Moderate cost within budget  (3) Low cost, well within budget |
| Installation (Labor) Cost | 10000 ₺ | [0-3] | (0) Exceeds budget significantly  (1) Requires a substantial portion of the budget  (2) Moderate cost within budget  (3) Low cost, well within budget |
| Ongoing Operational Expenses Post-Implementation | 15000 ₺ per month | [0-2] | (0) High recurring costs  (1) Moderate recurring costs  (2) Low to negligible recurring costs |
| Possible Total Point | 8 | | |

Table 8: Monetary Cost Criterion Checklist

|  |  |  |
| --- | --- | --- |
| System Components | Cost | TRY |
| Kinect Camera [52] | $37.99 + $48.58 shipping fee | 2503.60 ₺ |
| Adaptor (to connect Kinect to the streetlamp for power) [53] | ---- | 679.99 ₺ + 149.32 ₺ shipping fee |
| Programmable Logic Controller [54] | ---- | 1954.49 ₺ (includes two different wires to bind with other products) |
| Odor Repellent [55] | €19.95 + €14.95 shipping fee | 1124.75 ₺ |
| Total Cost (TRY) | 6380.82 ₺ | |

Table 9: Monetary Costs of Products Used in Construction of Solution One

|  |  |  |
| --- | --- | --- |
| Indicators | Score Interval | Comments |
| Products’ Costs | 1 | 28 systems 🡪 6380.82 ₺ x 28 = 178662.96 ₺ |
| Installation (labor) Costs | 2 | * Each setup will take ½ day. * HC electricians' daily salary is 350 ₺. (175 ₺ x 28 = 4900 ₺) |
| Ongoing Operational Expenses Post-Implementation | 0 | * Odor repellent should be renewed as it expires. * The approximate usage time of a box (500ml) will be 1 month [22] 🡪 €19.95 + €14.95 shipping fee (1124.75 ₺ x 28 = **31531 ₺**) per month as ongoing expense |
| Total Point | 3/8 | |

Table 10: Monetary Cost Criterion Checklist for Kinect-Based Deterrent System with an Odor-Repellent

|  |  |
| --- | --- |
| System Components | TRY |
| Rpi Microcontroller [56] | 1699.00 ₺ |
| Rpi Infrared Night Vision Camera [57] | 779.48 ₺ + 45.00 ₺ shipping fee |
| Ultrasonic Frequency Generator [58] | 5985.78 ₺ |
| Amplifier [59] | 718.79 ₺ |
| Module Casing (stainless steel plate x 3) [60] | 190 ₺ + 29.99 ₺ shipping fee |
| Total Cost (TRY) | 9448.04 ₺ |

Table 11: Monetary Costs of Products Used in Construction of Solution Two

|  |  |  |
| --- | --- | --- |
| Indicators | Score Interval | Comments |
| Products’ Costs | 0 | 28 systems 🡪 9448.04 ₺ x 28 = 264545.12 ₺ |
| Installation (labor) Costs | 2 | * Each setup will take ½ day. * HC electricians' daily salary is 350 ₺. (175 ₺ x 28 = 4900 ₺) |
| Ongoing Operational Expenses Post-Implementation | 2 | 0 ₺; no ongoing expenses |
| Total Point | 4/8 | |

Table 12: Monetary Cost Criterion for Machine Learning-Based Acoustic Deterrent System

|  |  |
| --- | --- |
| System Components | TRY |
| Rpi Microcontroller [56] | 1699.00 ₺ |
| PIR Sensors [61] | 3 x 24.66 = 73.98 ₺ |
| Rpi Infrared Night Vision Camera [57] | 779.48 ₺ + 45.00 ₺ shipping fee |
| Programmable LED Light Strips [62] | 4 x (454.41 ₺ + 78.60 ₺ shipping fee) = 1599.03 ₺ |
| Total Cost (TRY) | 4196.49 ₺ |

Table 13: Monetary Costs of Products Used in Construction of Solution Three

|  |  |  |
| --- | --- | --- |
| Indicators | Score Interval | Comments |
| Products’ Costs | 2 | 28 systems 🡪 4196.49 ₺ x 28 = 117501.72 ₺ |
| Installation (labor) Costs | 2 | * Each setup will take ½ day. * HC electricians' daily salary is 350 ₺. (175 ₺ x 28 = 4900 ₺) |
| Ongoing Operational Expenses Post-Implementation | 2 | 0 ₺; no ongoing expenses |
| Total Point | 6/8 | |

Table 14: Monetary Cost Criterion Checklist for Sensor and Artificial Intelligence-Based Visual Deterrent System

|  |  |  |
| --- | --- | --- |
| Indicators | Score Interval | Comments |
| Effect on Local Flora and Fauna and Ecosystem Balance | [0-2] | (0) High negative impact  (1) Some manageable impact  (2) No significant impact |
| Extent of Sustainable Material use and Resource Efficiency | [0-3] | (0) Unsustainable, high consumption  (1) Moderate sustainability  (2) Mostly sustainable, low consumption  (3) Fully sustainable and efficient |
| Possible Total Point | 5 | |

Table 15: Environmental Safety Impact Criterion Checklist

|  |  |  |
| --- | --- | --- |
| Indicators | Scores | Comments |
| Effect on Local Flora and Fauna and Ecosystem Balance | 1 | The system uses odor repellent which may temporarily affect local wildlife [19], [22] but isn't expected to have a long-term impact on the ecosystem balance [20]. |
| Extent of Sustainable Material use and Resource Efficiency | 2 | Electronic devices like the Kinect [18] camera and the control unit [14] do not typically require frequent replacement and have low energy consumption [63]. |
| Total Point | 3/5 | |

Table 16: Environmental Safety Impact Criterion for Kinect-Based Deterrent System with an Odor-Repellent

|  |  |  |
| --- | --- | --- |
| Indicators | Scores | Comments |
| Effect on Local Flora and Fauna and Ecosystem Balance | 2 | Ultrasonic frequencies target boars without affecting other wildlife or the ecosystem [24], as they are not known to impact flora or non-target fauna [29]. |
| Extent of Sustainable Material use and Resource Efficiency | 1 | Rpi [21] and other electronics are energy-efficient, though not fully sustainable. The use of a machine learning model for detection reduces resource efficiency [64] by causing activation even when unnecessary [25]. |
| Total Point | 3/5 | |

Table 17: Environmental Safety Impact Criterion for Machine Learning-Based Acoustic Deterrent System

|  |  |  |
| --- | --- | --- |
| Indicators | Scores | Comments |
| Effect on Local Flora and Fauna and Ecosystem Balance | 2 | PIR sensors and LED lights are non-intrusive to flora and selectively target wild boars, minimizing the impact on non-target wildlife and the ecosystem [31]. |
| Extent of Sustainable Material use and Resource Efficiency | 2 | The Rpi [21] and PIR sensors are relatively low-energy-consuming devices, and LEDs are energy-efficient [65]. The system operates only upon detection, conserving energy and minimizing unnecessary usage [31]. |
| Total Point | 4/5 | |

Table 18: Environmental Safety Impact Criterion for Sensor and Artificial Intelligence-Based Visual Deterrent System

## Appendix E – Action Plan Flowchart

## Hypothetical Gantt Chart for Wild Boar Deterrence System (Horizontal)

Figure 10: Action Plan Flowchart [66]

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