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MULTI-SENSOR FEEDER: AUTOMATED AND EASY-TO-USE BIRDS MONITORING TOOL FOR CITIZENS

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ABSTRACT:

Nowadays, more species are threatened with extinction than ever before in the human era. Especially breeding birds are considered endangered. At the same time, it is difficult to obtain sufficient data not only to raise awareness for this situation, but also to gain a better understanding and to develop potential countermeasures. We show how a citizen science based biodiversity monitoring for birds, using an automated and easy-to-use multi-sensor feeder, can look like. In doing so, we compare different configuration options concerning technical components, casing, as well as software to be used and present our suggested prototype: A smart bird feeder including an environmental sensor, a microphone, as well as a balance and a camera in a wooden case. It identifies the type of visiting birds using AI and publishes the recognized species, including all further collected data, on an open access website. The station can be reproduced by anyone at an affordable price in a Do-It-Yourself format, making citizens a key contributor to biodiversity monitoring.

1. INTRODUCTION

At this point in time, more species are threatened with extinction than ever before (IUCN, 2022). Anthropogenic impacts, including excessive land use and destruction of nature, have put our global ecosystem in dire straits. This is evident in the decline of breeding birds and the spread of invasive species (NABU, n.d.a). To detect these changes and to find patterns in the reasons for them, it is necessary to collect broad observational and environmental data, temporally and spatially. These data enables to evaluate the human impact on the global ecosystem (He et al., 2016).

To collect this data, three emerging aspects might be of interest. First, citizens science can play an essential role (Goodchild, 2007). Citizens can not only gather data, but also evaluate, and validate them. Second, microcomputers like a Raspberry Pi bring an enormous advantage (McBride and Courter, 2019). These can comprise multiple environmental sensors, a camera and a microphone to monitor the surrounding. Third, the advances of artificial intelligence (AI) help to evaluate the data (Miao et al., 2019).

Concerning all three aspects, research has already been carried out. There are already several citizen science projects ongoing to obtain temporally and spatially wide spread data concerning biodiversity. Citizens observe their surroundings and report their sightings. Common examples are the counting of birds in backyards (Sullivan et al., 2014) or the tracking of species like invasive alien species (Cardoso et al., 2017). Further, citizens can also validate the recorded data (iNaturalist, n.d.). However, a continuous data gathering is also time-consuming for citizens. Therefore, various tools have been developed to automatize the monitoring. Especially in terms of wildlife detection, there were some recent developments. The detection can either be done by the use of RFID chips (Youngblood, 2019), cameras (McBride and Courter, 2019) or by sound (Hill et al., 2019). Some tools even combine several sensors or connect observations with environmental data to detect animals (Wägele et al., 2022, Buxton et al., 2018). To evaluate the recorded data, the use of AI can be a game changer (Miao et al., 2019). AI is used in the form of neural networks, which take an image or sound file as input and detect whether an animal was represented on it (Cakir et al., 2017, Schneider et al., 2018). Further neural networks are able to detect the represented species (Şaşmaz and Tek, 2018, Willi et al., 2019). Thereby it is not mandatory to train an own model, since there are several image classification models available open source (Jakuschona et al., 2022b). A further approach is to combine different recorded parameters (e.g. appearance, motion, environment) to improve the accuracy of the detection (He et al., 2016). Generally, it is important to keep the monitoring tool affordable, so that every person can operate it. The senseBox is such a tool, especially for monitoring the environment (Wirwahn and Bartoschek, 2018). For animal monitoring, similar tools have been developed, like a low-cost bird monitoring tool using sound (Hill et al., 2019) or wild camera traps (McShea et al., 2016). By establishing an internet connection for the monitoring tool, the data can be published in real time (Sethi et al., 2018). Besides publishing, data can even be analyzed by using AI (Aide et al., 2013). Another crucial aspect is the presentation of the collected data. In order that the data are usable, they must be represented appropriately for researchers and scientists (He et al., 2016). Besides representation, further analysis is of interest, to enable the answering of research questions. An example therefore is the openSenseMap[1]. In addition to visualizations of the data, direct analyses via the web browser are possible (Wirwahn and Bartoschek, 2018).

The overall goal of this work is to contribute to the evaluation of the biodiversity in peoples gardens or balconies by monitoring birds and environmental factors. Additionally, the data should be freely accessible for anyone, thus supporting the work on several environmental and biodiversity related research ques-

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[1] https://opensensemap.org/

tions. To achieve this, we want to combine the previously presented aspects by developing a reproducible smart bird feeder, attached with several sensors to determine the species of visiting birds, while collecting data of the environment. Thereto the feeder, in the following also called station, is equipped with a camera to collect footage of the birds, a balance to measure the weight of them, a microphone to record the surrounding sound and a sensor to acquire environmental data, like the temperature and humidity. An important goal of this work is to present a station which is reproducible, affordable and Easy-To-Use for anyone. Thus, every citizen can built the station on her own, leading to a high distribution of stations.

2. APPROACH

With the publicly available data various research questions can be approached. For instance in a short term evaluation the differences between individual gardens and the correlation to factors like the size of the garden, the proximity to the next forest, or the diversity of plants in a garden can be analyzed. In a more long term observation also the development of bird species abundance within a year or over multiple years could be of interest. To built a reproducible and smart bird feeder different configurations of hardware and software components can be useful. Several of them were tested as part of this work with the aim to use components with a high usability, functionality and a reasonable price. The configurations tested can be divided in the sections hardware, software and casing and are described in the following.

Regarding the hardware, different microcomputers, cameras and elements to detect birds were implemented and compared. For the microcomputers three versions of the Raspberry Pi 4 Model B were used, differing in their RAM size: 2 GB, 4 GB and 8 GB. They also differed in price with €49.80, €59.90, and €83.90, respectively. The prices were taken from the online seller BerryBase[2] as well as the following prices. BerryBase was chosen as vendor for this project as it offered most hardware needed to reasonable prices and with good service. As cameras, three different Raspberry Pi Cameras were reviewed: Raspberry Pi Camera Module with 5 MP, Raspberry Pi Camera Module 2 with 8 MP and Raspberry Pi High Quality Camera with 12.3 MP. Respectively they cost €6.10, €24.90, and €54.20 with the HQ Camera needing additional lenses to mount on it, in our case a wide-angle lense for €25.70 increasing the overall price to €79.90. For the movement detection three different opportunities were implemented: A passive infrared motion sensor (HC-SR501), a camera pixel change detection, and the balance as motion sensor. The motion sensor costs €2.15, the camera and the balance are integrated to the station anyway. Concerning the balance we tested two different strain gauges. One that is designed for a maximum weight of 1 kg and one for a maximum weight of 500 g. For microphone, balance and temperature sensor, yet no alternatives were tested since the implemented ones are already cheap and functional. Nevertheless, beforehand, several considerations had to be made for instance on the maximum weight of the strain gauge.

Software-side there were also various opportunities that needed to be deliberated, especially regarding the processing of the camera data. First, which data is recorded by the camera, images or videos and second, where are they processed, at the station, on the microcomputer, or just at the server. This decision is also interacting with the considerations on which data are sent to the server and which image recognition model is applied when. Besides, different options came up with respect to the sources of the software used, especially of the image recognition models. Since the goal is to create a reproducible tool, everything incorporated should be available as open source and also the results and data were meant to be published as open access.

During the development of the prototypes also different options were tested for the casing. Different kinds of timber were used, the measures for the fodder silo and thus the respective capacity of fodder were varied as well as the angle of the silo bottom. Furthermore, different positions for the sensors were examined, especially the seat for the birds in relation to the position of the camera. Previously, it was necessary to determine how the balance needs to be implemented, i.e. where the birds should land to be measured. Two of the options were a plate or a perch.

Thus, the actual approach was to test the mentioned configurations of the components by implementing them in one of several prototypes and at the end deciding for the most useful option of each component, i.e. the cheapest one that was at the same time functional for the use case, as well as usable.

3. RESULTS

In the following, we present our development of a smart bird feeder (see Figure 1), which we consider to be as cheap as possible but at the same time does not suffer any drawbacks in terms of usability and functionality of collected data. In the following, we describe the technical and casing-specific components of the station and describe the software required for the operation.

Figure 1. Smart bird feeder visited by a European Robin (*Erithacus rubecula*) © WWU – Simon Jöcker (2022).

Concerning the hardware, the Raspberry Pi 4 Model B with 2GB RAM including a SD card with 32 GB memory is used as microcomputer, which collects all the data via the sensors and passes it on to the server. The Raspberry Pi Camera Module 2 with 8 MP is connected to the Raspberry Pi, which is mounted to the station with a 3D printer-made case including a thin layer of plexiglas. A strain gauge capable of weighing up to 1 kg in combination with an HX711 weight sensor is used as a balance. Besides, a digital I2S MEMS microphone is attached to the station, to record the voice of the visiting birds or general surrounding noises. In addition, a digital temperature and humidity sensor (DHT22) is attached to the station to measure environmental data. For transmitting the data from the sensors to the microcomputer, the hardware includes Dupont wires and a flex wire to connect the camera. Additionally, solder is needed to connect the sensors and cables for a long-term usage. Table 1 contains all technical components needed to operate the smart bird feeder.

[2] https://www.berrybase.de/

Technical components	Costs in €
Raspberry Pi 4B (2GB RAM + power adapter)	59,50
SD card, SanDisk Extreme 32 GB	8,85
Raspberry Pi Camera Module 2 with 8 MP	6,10
Strain gauge (1 kg) + weight sensor (HX711)	5,30
Digital microphone (I2S MEMS)	7,15
Digital temp. + humidity sensor (DHT22)	5,70
Connection wires (Dupont and flex wire)	3,50
Solder	0,50
Total	96,6

Table 1. List of all technical components needed to operate the feeder, including the costs.

The environmental sensor data is continuously logged and sent to the server, whereby the corresponding interval can be set by the user. As soon as the balance detects a weight, the camera is triggered and the microphone starts to record. The threshold for weight detection, beyond which a weight is considered as bird movement, can be defined by the user. At short intervals it is checked whether the threshold value for the weight is still exceeded. As soon as this is no longer the case, the recordings are stopped and the movement is considered to be finished. Data recorded by the camera is stored as video. The camera is recording to a circular stream, similar to the behavior of a dashcam. With a ring buffer, the camera records at any time, whereby the last five seconds are stored, but then directly overwritten, except motion is detected. If motion is detected, the five seconds are added to the video to record the bird's arrival as well. Subsequent to the movement, the videos are transferred to the server in their entirety, as the content of a data package. This package includes, in addition to the video, the audio file recorded by the microphone, the median of the weight measurements during the movement and the most current temperature and humidity values. For the execution on the Raspberry Pi the script language Python is used.

Material which is used for the casing is a beech wood multiplex plate (width: 9 mm), out of which the individual parts were cut. The interior is divided into two parts, firstly to provide space for the fodder, and secondly for the microcomputer including the cabling and sensors. The fodder is located in the front part, so that it can slide over a slight slope to the opening. In order to prevent fodder from falling out of the feeder in an uncontrolled manner, it has been limited by a narrow plastic lip. The bird can reach the fodder by landing on a wooden titled perch, which is mounted on the balance in front of the fodder. A cut-out at eye level of the visiting birds is included in the front of the case, to which the camera is attached. In the rear part of the station and below the fodder the technical components are installed. A hole in the bottom of the station provides access for a power cable, which is needed to operate the station. At this point the microphone, as well as the temperature and humidity sensor are also attached. The roof is easily removable to allow the refilling of fodder and the maintenance of the hardware. To enable the station to be mounted, a latch loop is attached to the rear. For weather resistance, the roof is additionally protected by a roofing felt and it is recommended to paint the station with a wood glaze. Mounting the station itself requires various screws and staples. An illustration of the station including the exact proportions is given by Figure 2. Table 2 contains all components needed to build up the case for the feeder.

Casing components	Costs in €
Multiplex plate (about 0.5 m^2)	25,00
Plastic lip	0,10
Wooden titled perch	0,50
Latch loop	1,10
Screws and staples	4,50
Roofing felt	0,50
Weatherproof wires box	5,99
3D printer-made camera case + plexiglas	5,00
Total	42,69

Table 2. List of all casing components needed to operate the feeder, including the costs.

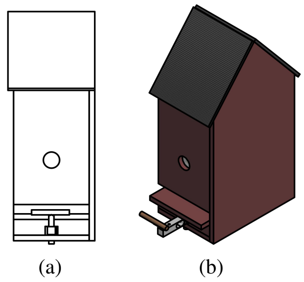

Figure 2. (a) Frontal view, (b) 3D-model © Sebastian Böing.

In order to process the data collected by the station, we have developed various methods and software for data storage, analysis and sharing. The data processing is done on a centralized server. For the operation of the server we exclusively use open source applications like Docker[3], Flask[4], and NGINX[5]. The used database which stores the data for the stations is a mongoDB[6] with a 120 GB SSD. However, the recorded video and sound files are not stored in the database, but as raw files on a 2 TB HDD storage. Communication with the server is enabled through a RESTful API and a website. The documentation for the usage of the API is available online (Jakuschona, 2022). On the server, created entities of the feeders can receive environmental data as well as movement packages. When movements are sent, the server identifies the species with AI. Therefore, we use an open source TensorFlow Lite model developed by Google using iNaturalist data and the structure Mobile NetV2 (Google, 2022). The videos recorded by the camera contain 30 frames per second. Every tenth frame is given to the model as input and analyzed with respect to the species. For every tenth frame, the top three predictions of the model are then temporarily stored, on condition that the model assigns them a probability of at least 30%, that they actually match the species depicted on the frame. For the whole video these stored predictions are compared and for each species the highest prediction is stored as the final prediction and added to the movement data package. Since the server receives several requests for species identification at the same time and in close chronological order, they are queued using Redis[7] and processed one after the other. Thus, it is possible that the identification of the species does not block the server, but new data packages can be accepted simultaneously. In addition to the storage, the server enables data access in two

3 https://www.docker.com/
4 https://flask.palletsprojects.com/en/2.1.x/
5 https://www.nginx.com/
6 https://www.mongodb.com/
7 https://redis.io/

ways. First, the data is downloadable as raw JSON via the API, which enables others to use it for their own research. Second, the data is published on an open access website developed by us, to make it easily inspectable for everyone (Jakuschona et al., 2022a). The website was built using the open source JavaScript framework React[8] including the Material UI[9]. The main element of the website is an interactive map, which was developed with the open source library Leaflet[10]. By clicking on one of the markers on the map, the individual stations and their collected data can be viewed. In this view, the last three movements are visible, including the recorded video and audio, as well as the detected species (including the probability that the proposed species actually matches the depicted bird). Besides, the trend of temperature and humidity is displayed over time and a counter is provided that lists the type of birds visiting the station over the last two days (see Figure 3). However, not only via our stations a upload to the server is possible, it is also open for the upload of data gathered by other systems. Further, there is the option to upload images of birds independently of the stations and to receive an prediction for the depicted species.

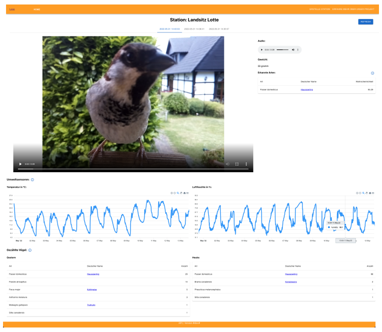

Figure 3. Website showing the station view including video, audio, detected species, trend of temperature and humidity, as well as a list of the visiting birds in the last two days.

Research code supporting this document is accessible online via GitHub as open source. The repositories to operate the station as well as the website and server are available in the GitHub Organization Birdiary (Stenkamp et al., 2022). The both repositories we created are additionally accessible via Zenodo (Jakuschona et al., 2022c), (Niers et al., 2022). Each of the repositories includes a README file with a description for the software and instructions how to contribute. In the repository for the station a corresponding manual is included describing how to build up the station and defining which parts are required (Niers et al., 2022).

Regarding the costs of assembling one station, the final price, when adding up the costs for the technical (€96,6) and casing components (€42,69), is about €139,29.

4. DISCUSSION

In this section, we discuss the reasons for the selection of the components described in the results and compare the chosen configuration to other options. As this is a report on work in progress it has multiple limitations and thus also future work which are the further subsections discussed.

4.1 Configuration

In terms of the microcomputer only the Raspberry Pi 4 Model B was tested yet as it is a common tool many people know and wherefore a lot of documentation is available. Therefore it is easier for users to adapt it on their own and to their needs, leading to a high usability. Moreover, many available sensors are compatible with a Raspberry Pi and their implementations are also documented well. In terms of the different RAM versions tested, the one with 2 GB was chosen because its processing power was sufficient for the use case as they were not that memory demanding. Thus the 2 GB version was the best option, as it got the lowest price.

Only Raspberry Pi cameras were tested so far because of usability reasons as they can be attached easily. The choice fell on the Raspberry Pi Camera Module 2 because with 8 MP it offers a high resolution to a reasonable price. In price-performance regard also the v1 is a reasonable choice and can be used equivalent to the v2 just with lower quality of the footage. The High Quality camera was no option as it is much more expensive than the other cameras and at the same time not very usable because of its size.

Several options are useful for the detection of birds, and it is necessary to weigh the pros and cons. First, the motion sensor can be used to recognize a movement, which could be attached near to the position of the camera. With the motion sensor described in Section 2, it was difficult to set the time delay and sensitivity, as these settings could only be made manually and were not changeable by software. Moreover, an additional sensor usually implies new errors, adds costs and additional effort. In contrast to the motion sensor, the camera has the advantage that it is already installed anyway. Thus a pixel change detection is possible without adding additional hardware. However, it is challenging to define the threshold at which a pixel change counts as motion and, moreover, the permanent monitoring of pixels requires a high amount of processing power. Nevertheless, motion sensor and a pixel change detection are meaningful options, if you want to recognize as many animals, and thus movements, as possible. Not only birds directly in front of the station, but also in the background can be recognized. This way, the rate of missed birds is relatively low. At the same time, other objects such as other animals or people can also be detected. On the one hand, this can be seen as a function extension (e.g. further usage as surveillance camera), on the other hand, it can be rated as an unnecessary processor load. In addition, there is another sensor which is installed either way, that can be used for motion detection, the balance. A change in the weight detected by the balance indicates a movement. Camera recordings are only stored, if a weight is detected by the balance. This procedure results in a lower number of false recordings and increased data privacy. However, this way, birds that do not land on the balance are not recorded. Ultimately, we decided to use the balance in our prototype for motion detection, as unnecessary recordings are avoided and the low processor requirement leads to low costs with regard to the required microcomputer.

In terms of the temperature and humidity data gathering we only tested one sensor, the DHT22. This is due to the fact that the sensor covers two environmental parameters (temperature + humidity), has a good accuracy (temperature: ±0,5 °C, humidity: ±2-5 %) and is affordable as well.

Two different strain gauges were considered for the balance, which are connected to the microcomputer via a weight sensor. One with a maximum weight of 1 kg and another with a maximum weight of 500 g. Finally, only the strain gauge with a maximum weight of 1 kg became an option, as the dimensions of the smaller strain gauge are not practical for the prototype.

[8] https://reactjs.org/
[9] https://mui.com/
[10] https://leafletjs.com/

Regarding the design of the feeding stations case, there were several options and factors to consider. First of all, with respect to the choice of wood. Initially, a multiplex plate including a smooth film layer of phenolic resin was used. However, since the dark color causes the station to heat up, the phenolic resin layer was not used within the final prototype and painting with a wood glaze is recommended instead. Second, a compromise had to be found regarding the general size, to ensure that there is enough space for fodder and hardware, but at the same time the station should be attractive. Generally, the smaller the amount of wood, the cheaper the overall costs. Third, a reasonable design regarding the roof had to be found, whereby the main focus was set on the angle and length. With respect to the angle, it was concluded that 90 degrees proved to be useful, as this angle makes the roof both easy to install and subsequently easy to remove, for checking the fodder and hardware. Concerning the roof length, some overhang at all sides turned out to be useful to improve the weather resistance. The front side sticks out a little further than the back side. Thus, on the one hand, the fodder is protected at the front, and on the other hand, the possibility of mounting the station with the back on a house wall is preserved. Fourth, the design of the fodder silo is crucial for the function of the station. As already indicated, there is a trade-off between reserving enough space for fodder and leaving enough space for the hardware. Additionally, the angle of the fodder silo bottom must be chosen in a way, which lets the fodder roll out. Besides, the length that the bottom sticks out of the station is decisive. A longer bottom offers more fodder but also allows birds to land on it. Thus, the birds are not recognized, as they do not land on the balance. Moreover, then the birds feet and potentially also dirt is in the fodder, which is not hygienic. It is advisable to attach a protection (e.g. a small plastic lip) to the end of the bottom, which prevents the fodder from falling down at the edge. Fifth, mounting the balance reasonably to the case is essential to allow the birds to visit the station at all. The landing spot needs to be far enough away from the camera, to allow depicting the whole bird on the recordings. At the same time the spot needs to be in the right distance to the fodder, to allow birds of different size to reach it. The position is limited by the length of the strain gauge, whereby mounting a tilted perch or an plate on it can raise the distance. Both a perch and a flat plate were considered, with the perch ultimately having more advantages. Due to the perch the birds are in the focus of the camera if they land on it, which is not always the case for a plate. Additionally there are no impurities influencing the measurements, since the surface area is less for a perch than for a plate. Besides, it is more hygienic as with a plate, which is more likely to be tainted. Lastly, there are several options for attaching the station. Generally, it is advisable to attach a latch loop to the back of the station. Thus, the station becomes mountable to a wall, wooden post, or fence.

In addition to the hardware, the software is a key element in the functioning of the station. First of all, different factors and trade-offs need to be considered regarding the processing of the camera. A first trade-off exists between recording videos or images. Videos include more information and are more interesting for users, while images can be easier send via a network, as less disk space is needed. Additionally, a video enables multiple frames as model input, while there is only a single frame in case an image was recorded. An image often leads to less precise predictions since not the important parts of the bird are represented in this image. By using a video there are several options to calculate the percentages of the final prediction. Currently, the maximum prediction is used, which can lead to errors. If a wrong bird is detected with a high probability on one of the frames, it still is the proposed species in our solution, even when the correct species is detected in other frames, but with a lower probability. One solution could be to use an average value of all images. A further question is whether the processing of the camera recordings should be carried out on the microcomputer or on the server, and if so, to what extent. Processing the recordings on the stations microcomputer allows to send only the extracted information (e.g. the species predicted by the model). Thus, a WiFi connection is not mandatory for the data transfer, as less amount of data can be also send via low-power networks like LoRaWAN. However, applying an image recognition model on a microcomputer can be overcharging in terms of power and processing demand, especially with a high frequency of visiting birds. A compromise for processing on the microcomputer may be to run only a simplified recognition model on the microcomputer, to reduce the data load to be sent. An object detection model identifies on the microcomputer whether a bird is depicted on the image, only then the image is sent to the server and analyzed regarding the species. As described in Section 3 we used a ring buffer to show the landing approach of the birds. Certainly this results in an increased processing and storage demand, since the camera is running continuously, but there is also added benefit for the detection of birds, both in terms of the model and the users. Concerning our prototype, we decided to store videos including the arrival of the birds and to send them via WiFi directly, without processing on the microcomputer, to the server. This was the best option in our case, as it allows as many frames as possible to be investigated for birds and enables users to view visitors of the stations as detailed as possible. Besides, alternative networks such as LoRaWAN and cellular are not implemented within the scope of the station at the moment. Second, there is a decision to be made about how to calculate the weight of the visiting bird. The station continuously collects the values that are returned by the balance. One could now take the highest value or the lowest value, but this probably does not correspond to reality, since these were probably generated during the arrival and departure of the birds. Therefore, we decided to use the median of the weight recordings during a movement, which is ultimately entered as the value for the weight in the movement data package. Third, in terms of the database, we decided to use a MongoDB instance, as it is object based and flexible, generally in terms of the data handling, but also in terms of the format (video, sound, geospatial data). Concerning sending the data we decided that the environmental data are sent continuously in an interval defined by the users, independent to the sent data packages of a recognized movement. Certainly, the environmental data could have been sent only within the movement data packages, but we wanted to send them continuously. This results in an increased processing and data transmission rate, but the data can thus be used for relevant research questions e.g. about the correlation between the frequency of visiting birds and environmental factors. Fourth, an adequate solution for the visualization of the stations data needed to be found. The visualization implementation described in Section 3 is certainly work in progress. However, it is already noticeable that the continuously increasing amount of data and its real-time visualization pose a challenge. At the moment only the last three movements are available via the website, which results in a quite satisfying retrieval time until the recordings are loaded and visualized. In the long term, it is desirable that also older movements are viewable in an appropriate waiting time. Currently, older movements are only viewable via a direct API call. In this context, it would also be desirable to have an interface that allows you to download the desired data depending on the station, period and species.

Another crucial issue is the data privacy. As the stations are built up in the gardens of private persons, recordings are done and the position of the station is visible via our website, it must be ensured that the privacy of the citizens is ensured. Therefore we take several measures. One of the steps is that the focus of the camera is set at the level of the perch position. This way, the objects in the background are not clearly visible, but only blurred. In addition, a dialog during the registration of the stations ensures that the citizens in whose garden the stations are located agree to the collection and publication of the data. It should be noted, that citizens independently set the location of the station on a map, so they do not necessarily have to provide an exact location and can also choose a neighboring open space such as a park. Besides these measures, there are a number of other actions that can be taken to improve the privacy. One possibility would be that the locations of the stations are not specifically shown on the map. An example is shown by Sensor.Community[11], which displays the location of its sensors in the form of large-scale hexagons, so that the exact location is not publicly accessible. Another option is to run a light weighted object detection on the station, which checks if there are people or other unwanted objects on the recordings, both for the image data and the audio files. The data is then only sent to the server if unwanted objects have not been detected. Or the unwanted objects are blurred and thus made unrecognizable.

One further focus of our research is to ensure that the software to operate our station, the data collected from the stations, as well as appropriate instructions on how to build the station are freely available to everyone. Not only do we provide software and all data freely, but also the software packages used for implementation are open source (see Section 3). The data can not only be used by anyone who is interested, but the station can also be set up by anyone. Thus, the project can be carried on in a citizen science approach and the amount of data increases continuously, which makes the station even more valuable for researchers.

4.2 Limitations

In our research, we encountered several limitations, particularly concerning the reproduction of the station, the limited amount of species caused by various factors, and the usage of sensors.

One of the research goals was to develop the station in a reproducible manner so that anyone can replicate it using a DIY manual (see (Stenkamp et al., 2022)). Generally, this is true for the station, including the instructions provided, but there are also some limitations. Thus, in our current configuration it is necessary, to use a 3D printer for producing the case of the camera. Furthermore, several tools (e.g. drill, saw, screwdriver) are needed to assemble the station, which, however, should be available in a well-equipped home workshop. Another limitation is the focusing of the camera, this adjustment has to be done manually by a rotating mechanism on the hardware. Certainly, a camera with auto-focus could have been chosen, but it would have significantly increased the overall costs of the station and taken up more of the station's space. Furthermore, it is important to mention that the prices for the wood mentioned in Table 2 are only the material costs. Here it must be considered that the cutting of the wood certainly takes a certain amount of time and/or causes costs.

Furthermore, it is important to mention that the feeder is not reachable for every bird and therefore the diversity of visiting birds is limited. The perch on the balance is only made for small to medium sized birds. This is because the bird can stand out from the perch a maximum of 8 cm until it reaches the front wall of the station. Additionally, larger birds would not find traction on the currently used perch. However, not only the dimensions of the station but also the fodder and the location of the station used limit the visiting birds. Depending on the season and bird species, different fodder is suitable for usage (NABU, n.d.b). In this context, it is also important to note that different fodder also affects the station differently (e.g. fat fodder and mold could contaminate the stations wood) and the maintenance time (e.g. for cleaning) varies. Besides, the location is also a limiting factor for the number of birds visiting the station. Orientation in relation to the cardinal direction, solar radiation and surrounding vegetation influences whether birds perceive and accept the station (NABU, n.d.c).

Moreover, it is important to mention that the installation of the sensors must be considered carefully in many respects. It must be ensured that they are mounted weather-protected, but at the same time collect valid data. Currently, the microphone as well as the temperature and humidity sensor are installed underneath the station. This ensures a certain weather stability, but a possible heating of the station due to solar radiation and heating of the microcomputer can lead to increased temperature measurements of the sensor, which then no longer correspond to the actual surrounding temperature. At this point, appropriate heat protection and isolation must be considered so that the temperature sensor does not produce invalid data, due to unwanted disturbing factors by the station. With regard to the microphone, it must also be questioned whether mounting it below the station is the best way to record the songs of visiting birds. Another issue to consider is that the recorded song does not necessarily have to be attributed to the visiting bird, but can also be caused by a bird from the surrounding area. A solution could be to determine either by the loudness of the song or sighting and analysis of the image recordings whether the song originates from the visiting bird.

In addition, it must be mentioned that the research is conducted as citizen science project. It is important to keep in mind that stations may send invalid data or no data at all for a certain period of time and that it may take some time until errors are corrected. This is because citizens are involved in a volunteer format. However, as already mentioned in Chapter 4.1, it is the active participation of citizens that enables a continuous flow of scientific and citizen-led improvements, a broad data collection and the success of this research project in general.

4.3 Future Work

Based on the findings described above, several options for future work come up.

A first possibility is that additional sensors can be attached to the station, to answer various questions and dependencies related to the visiting birds. These include, for example, a particulate matter sensor, a UV sensor or a loudness sensor. In addition, the functionality can be made more efficient. Depending on the brightness at the location of the station, one could use a brightness sensor to stop the operation of the camera as soon as

[11] https://sensor.community/en/

it becomes too dark to recognize anything on the images. However, this can probably also be controlled via software with the time of sunset and sunrise. It is also conceivable to install a thermal or infrared camera instead of, or even in addition to, the current camera. This way, recording during the night or at locations with a low brightness could be made possible.

What should also be strongly considered is a standalone mode of the station. This implies that the station can be set up in almost any place, without the need for a WiFi connection and a plugged-in power supply. On the one hand, an alternative network connection must be found. Possible options are, for example, LoRaWAN (whereby the low data transmission rate must be taken into account) or the integration of a SIM card, and thus the use of cellular networks. On the other hand, a power supply must also be ensured. For this purpose, it is conceivable that the station is operated via a solar panel, which is installed on the roof, for example. Battery operation together with a solar panel or on its own is also feasible. Either way, the standalone mode is a very interesting specification, as this way the station becomes usable in a variety of locations, allowing data to be collected even in exposed locations where manual observation by research teams is difficult or even impossible.

Another expansion possibility is the detection of individual birds. At the moment, the species of the visiting birds can be identified. If further analysis of camera footage or alternative sensors such as LiDAR could be used to identify individual characteristics of visiting birds, it may be possible to recognize individual birds as returning visitors to the station.

The validation of the collected data is another aspect that could be improved. Currently, a model determines the species of the visiting bird, but there is no further validation regarding the correctness of the models prediction. However, there are several possibilities for such a validation. One idea would be to use the other sensors. If a certain species is detected, the recorded weight is checked to determine whether it is at all suitable for the predicted bird. It is also conceivable to check whether the predicted bird even has its habitat at the stations location. In addition, validation by persons is conceivable. Citizen scientists who have been identified as experts in the field of ornithology can review the predictions of the model on the website and verify them if they are correct. Validation by further models is of course also conceivable.

However, not only the use of already existing image recognition models, but also the complete or partial training of a model with data already collected by the stations is conceivable. This way, the accuracy and thus the prediction of the model can be increased, since the extent and location of the training data would then be more similar with the data to be interpreted than with the current training data.

In addition to the use of image recognition models, it is also conceivable to use recognition models for the voices and songs of birds. This may then allow conclusions about birds that are in the surrounding area of the station, but do not visit it directly.

Which birds visit the station and which do not, although they are in the vicinity of it, is one further research aspect. In order to gain knowledge in this context, 21 stations have already been set up in a test study together with citizen scientists. In this study, the citizen scientists observe the bird occurrence in the surroundings of the station within the framework of the Garden Bird Hour (NABU, n.d.d) (a biannual bird counting campaign organized by the Nature and Biodiversity Conservation Union of Germany), which allows corresponding findings to be identified with regard to the question described before. The birds that have already visited the stations without any doubt at this point in time include the European Robin (*Erithacus rubecula*), Eurasian Blue Tit (*Cyanistes caeruleus*), Chaffinch (*Fringilla coelebs*), European Greenfinch (*Chloris chloris*), Eurasian Blackbird (*Turdus merula*), Eurasian Jackdaw (*Coloeus monedula*), Eurasian Magpie (*Pica pica*), Eurasian Great Tit (*Parus minor*), Marsh Tit (*Poecile palustris*), House Sparrow (*Passer domesticus*), Eurasian Wren (*Troglodytes troglodytes*) and Eurasian Bullfinch (*Pyrrhula pyrrhula*).

In addition to participating in the Garden Bird Hour, the citizen scientists are pushing the research project in further aspects. After a few months of testing the station, a workshop is held with the citizen scientists involved. Within the scope, the station is discussed, not only the data collected, but also the possibilities for improvement in terms of hardware and software. Citizens are encouraged to customize the station according to their ideas anytime and to share their ideas and experiences with these adaptations during the workshop. Thus, first long-term experiences with the station are being collected, which will contribute to the development of the next generation of the smart bird feeder.

In the long term, it is also conceivable that other living organisms, will be detected. Currently, some other animals, beyond birds, already visit the station, but they are not always detected because the recognition process has not yet been optimized accordingly. But with some small adaptations to the feeder it could be used to detect or count different mammals like squirrels or insects like butterflies and bees.

5. CONCLUSION

Motivated by the fact that more species are threatened now than ever before, we have shown how a smart bird feeder operated by citizen scientists can look like and support biodiversity monitoring using AI. We have presented how we tested different configuration options in terms of used hardware and software with the aim to use only components with a high usability, functionality and a reasonable price. It became clear that a smart bird feeder, including an environmental sensor, a microphone, as well as a balance and a 8 MP camera in a wooden case, represents a suitable solution for AI-supported citizen science based biodiversity monitoring. A sufficient network connection proved to be essential, not only to present the data and recordings of a bird visit in a visually interesting way for the citizens, but also to enable the most accurate species identification as possible. However, the key aspect is that the station itself is reproducible in a DIY format at a reasonable price and that the collected data is openly available. With this approach, enabling many citizens to participate in the study, a large amount of data is collected and a variety of questions can be answered by research teams and society.

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