ICEDIG.EU Innovation and consolidation for large scale digitisation of natural heritage

Grant Agreement Number: 777483 / **Acronym:** ICEDIG
Call: H2020-INFRADEV-2017-1 / **Type of Action:** RIA
Start Date: 01 Jan 2018 / **Duration:** 27 months

REFERENCES:
MILESTONE **MS11**

Work package **WP3** / Task **T3.1.2** / Lead: **University of Helsinki**
Deadline **M4**

Specifications of tests on automated methods for digitisation of pinned insects

MILESTONE - MS11

Authors:

Hannu Saarenmaa, Zhengzhe Wu, Anne Koivunen, Luc Willemse

Funded by the Horizon 2020 Framework of the European Union
H2020-INFRADEV-2016-2017
Grant Agreement No 777483

ICEDIG.EU

Abstract

This milestone report lines out the experiments which the ICEDIG project will consider and eventually carry out in order find new innovations in mass-digitisation of pinned insects. A ten-fold increase in the speed of their digitisation is sought. The report begins by identifying the challenges, which stem from the fact that pinned insects are basically 3D objects and their numbers in collections are huge, up to 1 billion objects in Europe. Based on recent reviews, state-of-the- art in their digitisation is briefly covered. Important new technologies which seem promising in insect digitisation are described. We conclude that achieving a breakthrough in insect digitisation probably requires a combination of existing and new technologies in novel workflows.   Finally, we identify six such possible approaches, scoping their features, applicability, possible benefits and limitations, and make recommendations whether and how to try these approaches in experiments during the ICEDIG project.

This report is a live document which will be updated when new information is obtained. It will gradually evolve into the deliverable report D3.5 “State of the art and perspectives on mass imaging of pinned insects”, at month M19 of the project.

Table of contents

Funded by the Horizon 2020 Framework of the European Union
H2020-INFRADEV-2016-2017
Grant Agreement No 777483

1. Introduction

The ICEDIG project is looking for solutions which would allow digitising a significant part (such as 50%) of important public collections in foreseeable time (such as 25 years). This would require a digitisation capacity ten times faster and cheaper than what exists today.

By "digitisation", we mean here imaging and limited data entry for the taxon name, major biogeographic area, and other possible elements which are common for the drawer, box, or unit, and can be entered for a bulk of specimens in a rapid fashion, without significant slowing down of imaging. Any detailed, and time-consuming data entry would follow later.

More than one half of all specimens in scientific collections are pinned insects. (In Europe this means 500-1,000 million such specimens.) Today's fastest mass-digitisation (i.e., imaging) systems for pinned insects can achieve 70 specimens/hour and 500/day by one operator (Tegelberg & al 2014, 2017). This is in contrast of the 5,000/day rate of the state-of-the-art mass-digitisation systems for herbarium sheets (cf. Oever & Gofferje 2014).

Therefore it is critical for ICEDIG and DiSSCo to find ways to speed up insect digitisation by a factor of ten.

The slowness of imaging pinned insects follows from the fact that they are essentially 3D objects. Although butterflies/moths, dragonflies and similar large-winged insects can be prepared (spread) as 2D objects, the fact that the labels are pinned under the insect specimen makes even these samples 3D. On the other hand, these large-winged insects easily mask all labels, necessitating removal of labels in any approach. For instance, among the 10 million insect specimens held by the Finnish Museum of Natural History, the proportion of specimens belonging in these large-winged groups is about 30%. Furthermore, in some other orders of insects (beetles, bugs, wasps, grasshoppers) there also are substantial proportions of large species which also can block viewing of the labels.

In imaging, the labels are often removed manually, which slows down the imaging process. If the need for manual handling of the labels can be skipped, we can easily multiply the imaging speed. There still remains the need to attach a label of unique identifier in the sample, but that can be done quite fast. So the first question to ask is, how can we avoid handling the labels?

This document outlines several possibilities for achieving this. We first review the state-of-the-art, and their discussion of future potential. We then discuss promising technological advances, such as conveyors, robotics, machine vision, multispectral scanning, 3D modelling in large scale, etc, and possibilities of their integration. Some of these new technologies have not yet been tried for insect digitisation. In a closely related report of the ICEDIG project (Nieva et al. 2018), 3D techniques have been assessed in detail, determining the state of the art of the technologies, workflows, collection types, and existing efforts, and available commercial actors.

The answer may be that we would not use just one approach to digitise all insect collections, but choose the method optimally based on criteria such as wing size, number of labels, etc. This approach was used by Hereld et al. (2017) who classified (a sample of) the Chicago Field Museum insect collection by the physical characteristics of the specimens, and then recommended varying approaches that best fit each specimen type. Some of the best practises that will turn up may consist of using a specific imaging protocol in combination with a data entry protocol, studied by the ICEDIG Work Package 4. Although imaging protocols and data entry protocols can be carried out completely independently, but there may be specific combinations of imaging protocols and data entry protocols that can be more efficiently combined than others.

Finally, we define a small number of potential experiments of the most promising technologies. These tests can then be discussed with potential collaborators and commercial actors, and some of them may be turned into prototypes. The successful prototypes may finally form the basis of operational systems in the DiSSCo infrastructure.

2. State of the art in insect mass-digitisation

Here we briefly describe the state-of-the-art in insect mass-digitisation from the perspective to identify most promising approaches that have not yet been tested fully. There have been a number of earlier reviews on the subject (e.g., Blagoderov & Smith 2012, Holovanchov et al. 2014, Brecko & Mathys 2016) and we do not intend to repeat their analyses. Instead, we identify from the discussions and conclusions of earlier studies the way forward for actual new tests, which might show the way forward.

- **Manual digi-streets.** Most insect mass-digitisation still happens manually. Workers enter metadata from specimen labels and often also take pictures. When a number of workers perform this in an organised way, we talk of "digi-streets". Their performance can be quite fast, for instance, in 2014, the 45,000 specimens in the bumblebee collection of the Smithsonian Institution were imaged in just 40 days (Kutner 2014). The number of workers employed was not reported, though. At Naturalis, data entry of 850,000 has been done using a similar approach. When fine-tuned, digi-streets can be quite effective, but their performance is linearly dependent of the human workers employed. Typical data entry pace is 200 specimens/day and photographing pace 70 specimens/day (ref.).

- **Whole-drawer scanning.** Reviewed by Holovanchov et al. (2014) this approach takes images of whole drawers of insects, consisting perhaps hundreds of specimens. The five systems that have been described include GigaPan, GigaPanMicro, Sat-Scan, DScan (Schmidt et al. 2012), and use of a high-resolution medium format camera such as Hasselblad. The camera is either fixed, moved on a fixed motorised mount, or moves on rails. The output is one huge-resolution image of the entire drawer. Supporting software such as the open-source Inselect package can then be used to crop and segment the images so that pictures of individual insects can be produced. This approach is very effective and used in a number of museums around the world. The drawback is that no images of the labels will be produced. However, augmenting this method with camera tilting for label capture might offer a wider range of applications. An open call for proposals to demonstrate such system, with a $1 million award for the winning bid, was launched by the "Beyond-the-Box" project in 2015 https://beyondthebox.aibs.org/, but received no entries!

- **Conveyor-driven imaging.** Despite the success of conveyor-driven imaging in plant imaging since 2008, only one such system has been developed for insects (Tegelberg et al. 2014, 2017). Individual insects that have been mounted on specific pallets are carried into an imaging station, where they are automatically photographed using up to three DSLR cameras. If labels cannot be seen this way, they must be manually detached and placed on the pallet. Maximum performance of two operators has been 500 specimens/day when handling only one label.

- **3D mass digitisation.** This approach is currently being studied by several research groups. 3D imaging. Systems like ZooSphere (Kroupa et al. 2014) have achieved 3D "high precision" 3D imaging, but doing that in massive scale is another matter. ZooSphere does not produce a separate 3D model of the object. Developments at Argonne National Laboratory (Hereld et al. 2017) and at Darmstadt Technological University (ref.) are underway, and are looking into producing 3D models which would then be rendered with images.

3. Promising new technologies

- **Robotics.** There still is excessive need for human operators in insect digitisation, in particular when labels need to be handled. This is the case even in feeding insect samples into an automated conveyor line. There are several areas where robotics could potentially help in insect digitisation. These include handling of labels, moving cameras in unobstructed view positions, and transporting drawers and units. There may be other opportunities as well.

    - Handling of labels (removing and reattaching) is high-precision work on delicate objects and therefore slow, requiring practice and careful hands. Handling of insects is a bit less demanding, but still a job for a professional. Handling of units and drawers can be trusted even for an inexperienced worker. Which ones of these can be trusted for a robot? There are high-precision robots of suitable size available on the market, which are already being used for medical and other demanding tasks. They could potentially be used for handling insects, but the difficulty rises from having proper 3D information of the exact positions of the specimens and labels, and then combining the robot movements accordingly.

    - A related, but much less demanding job is to move a small camera in proper viewing position. Handling of insects would be avoided, but still there must be very accurate information of the position of the specimens.

    - Handling of units and drawers is an easier job, but the benefits would require that the entire collection is turned into an automated warehouse. Currently, collection cabinets and drawers have been designed for human operators. Letting a human-size robot to handle them would require redesign of both. If this is possible, moving materials in and out of the collection could yield significant benefits. (This is being addressed by ICEDIG Task T3.3.)

- **Machine vision and automatic image analysis** have penetrated the society in a big way in recent years. This is most notable in traffic, where speed traps, police cars, and road toll stations already scan the register plates of vehicles in real time. Autonomous vehicles are being tested in real situations. Lane-assist is commonplace. Extending the use of these technologies into digitisation is an obvious step. Labels could be automatically extracted from images of pinned insects, corrected for position and angle and then automatically transcribed. Also identification of the species has been shown to be possible in some cases.

- **3D modelling, lidars.** Building of 3D models of individual insects and units / drawers may be needed for two reasons: Proper orienteering of robot arms and having a digitised model of the insect itself. Both can be approached by building a 3D model of the target. Building a 3D model is different from just photogrammetry of an 3D object – there will be a digital object with coordinates in 3D. For controlling the movement of a robot arm, rendering the surface of the object is not needed but when digitising the actual object, rendering is very much needed. Lidar technology (Light Detection and Ranging) is based on laser beams and is widely used in landscape-scale digitisation of terrain and vegetation. It can also be used in small scale. /*to be continued, references to cultural object digitisation are needed*/

- **Terahertz, time-gated, multispectral imaging**. Accroding to Redo-Sanchez et al. (2015), terahertz time-domain spectroscopy (THz-TDS) is a leading method for spectroscopy, imaging and nondestructive testing in the frequency range of 0.1–10 THz. The method can detect structural defects in foams, wooden objects, plastic components, composites, pharmaceutical products' coatings and cultural artefacts. In contrast to infrared-based time-of-flight cameras, optical coherent tomographic techniques and X-ray techniques, THz-TDS provides both fine time resolution and broadband spectral signatures for a variety of dielectric materials. These advantages have motivated researchers to use computational techniques to empower the yet-maturing THz hardware. Despite the prevalence of sub-millimetre layered structures in industry, biology and objects of cultural value, conventional THz-TDS is incapable of deep content extraction for three wellknown reasons: signal-to-noise ratio (SNR) drops with depth (or increasing number of layers), the contrast of the content is much lower than the contrast between dielectric layers, the content from deeper layers are occluded by the content from front layers. Therefore, Redo-Sanchez et al. (2015) introduce a time-gated spectral imaging technique that overcomes all of these challenges to extract occluding content from layers whose thicknesses and separations are comparable to the wavelength.

4. Experiments

Below we describe a number of potential tests with various new approaches. The tests described are not all similar, and some derive from other tests and combine various technologies. They deal with imaging specimens and units, static setups, and conveyor belt-driven approaches. We assume that achieving a quantum leap in insect digitisation probably requires a combination of various advanced technologies, such as conveyors and 3D photogrammetry, and most tests envisioned below follow this approach.

4.1. Minimal labels

a) Features

In this approach we place individual specimens in imaging station (manually or by conveyor) and image the specimens without removing the labels. One shot will be made from above and another from a 30-degree angle from the side. This allows capturing the topmost label. If the labels are spaced out well, maybe also other labels can be captured.

b) Applicability

This approach has been used in operational scale while imaging the entire Coleoptera collection of Gunnar Blomqvist at Digitarium (Tegelberg et al. 2014). Using conveyor-driven imaging, a total of 12,400 specimens of all sizes (representing the entire beetle fauna in Finland) were processed in 50 days, giving a rate of 248 specimens /day. This rate is rather slow, since the workers were not experienced entomology curators, and time was spent spacing out the labels for optimal viewing. Also time was spent in reorganising the collection from original boxes to units.

This approach can be applicable in situations where the collection is rather uniform and there is only little information in labels, such as collector's field number, and there are not too many labels. This approach will also work best for other than large-winged insects, which actually constitute 70% of all specimens.

c) Expected benefits

2-3 fold speed increase compared to the basic practice of removing and reattaching labels.

d) Difficulties and limitations

Labels below the topmost will not necessarily be imaged. How much data will be lacking because of this depends on the collection. If the top label contains all the essential information, it may just be enough. Furthermore, additional data capture done on the side of imaging, such as entering the taxon name and major geographic area, may supplement the imaging process so that this approach is worthwhile.

e) Recommendation

We already know how to do this, so there is no need for further tests. The question is whether it is worthwhile to obtain such a limited data. When optimising the costs of the total digitisation effort, this approach might have significant role in digitising many collections of certain kinds of specimens at low cost. So this approach should be taken into account in final cost books. Putting that in more general way, this implies that we have to describe collections that are fit to be tackled by this process. One of conditions would be that the technique is ideal for insects with only one label.

4.2. Maximal webcams

a) Features

This approach is similar to the previous, but adds a maximal number of small webcams for capturing the labels from a number of different angles and directions. So there would be one image from above of the specimen and as many as ten images of the labels. So, if the labels are not entirely stacked over each other, there is a good chance that they will get imaged. Also video could be captured.

b) Applicability

The imaging station will be covered by a number of webcams, so placing the specimen there will require careful movement. This can probably be achieved by conveyors, which would also facilitate video capture.

c) Expected benefits

Benefits are similar to those of the previous approach. However, in this method, there is a better change of seeing more labels than the top label. This approach may also work better for large-winged insects.

d) Difficulties and limitations

There will be a large number of images from varying angles, and their viewing will require time in transcription. This can be alleviated by image processing that turns the images the right way and corrects the viewing angle.

e) Recommendation

This is a low cost option which will certainly yield valuable experiences, and should be tried.

4.3. Imaging of units

a) Features

This approach is similar to the previous one, but instead of placing individual insects in the imaging station, entire units are imaged. (“Units” are small boxes or trays contained in drawers of collection cabinets, and are being used in most major insect collections.)

Individual insects would not be handled. Tagging the individual insects with unique identifier labels would be deferred to a later stage. The labels could be printed on a sheet which would be placed under the unit. The units would be labelled with identifiers as well, which would facilitate rapid retrieval of their data, when the specimens need to be curated.

One or a few shots are made from above and any number of shots from the side using small webcams.

It follows that the images contain many specimens. From the top image the individual specimens can often be automatically picked up using image processing (segmentation). After this step, their positions in the unit are known, which may assist in automatic segmentation of also the labels from the images made by the webcams.

b) Applicability

This approach is widely applicable for any insect collection which already has been organised in units. It fits well with conveyor-driven imaging.

c) Expected benefits

As this eliminates all handling of individual insects, this approach would achieve the required ten-fold speed increase, and probably more. As such it necessarily is worthwhile to try.

d) Difficulties and limitations

This approach requires heavy computation in the segmentation of the top images, and in a possible creation of a 3D model of the unit, and in extraction of label images of many specimens. The resolution of the top image will be lower than in the previous approaches.

There are multiple sizes of units in each drawer. It would be impractical to digitise only some units in a drawer. This can be a problem if conveyors are being used to move the units in the imaging station. Therefore multiple parallel conveyors of various widths may need to be used.

Printing and attaching labels to specimens in the units will be complicated, and if postponed to future, will require careful instructions for the curators.

e) Recommendation

This approach seems to offer a large benefit, and should be tried. There are some technical obstacles in the image processing, but these can probably be handled using available technology.

4.4. Camera in robot arm

a) Features

The above approaches use fixed cameras, and are suitable for installation in a conveyor setup. However, this approach employs only one camera, which would be installed in a robot arm. The camera would take a large number of shots from different angles of the specimen that would be mounted in stand. This would be quite similar to the ZooSphere system, but not aim for precise 3D digitisation, and hence only require a few good shots that can be taken fast.

In a different variant, which could be tried after the system work, the robot would work on a unit or on an entire drawer.

The key feature of this approach would be communication between the robot arm and the camera. Such systems are being used in medical and industry applications. Ideally, the system would need to understand what it sees and steer the imaging in real time.

In an extreme variant the robot arm would not only carry a camera, but an instrument to space out the labels as needed for good imaging.

b) Applicability

This approach might fit all cases of imaging insect collections. However, these cases (individual insects, units, drawers) should probably be treated differently, but at the moment we do not have enough knowledge to specify them in such detail.

c) Expected benefits

This could become one-size-fits-all solution for imaging insect collections. The robot could be left alone to do imaging 24h/365d. Only loading new units and drawers would require small breaks.

d) Difficulties and limitations

Robots are still expensive.

The communication between the robot arm and vision system requires an advanced data processing system. These are probably available from research and industry, but will require adjustment and testing. There may be a high cost in acquiring such a system.

e) Recommendation

This approach should be tested in cooperation with an advanced robotics and machine vision lab.

4.5. Cameras on rails

a) Features

This approach is similar to the previous one, but does not employ a robot arm. Instead the camera is placed on rails moving in 2D, possibly even 3D, and which would work over a drawer. This is basically the SatScan system, but adds the capability to tilt the camera to also see the labels. A smaller, simpler variant would work only on a unit.

b) Applicability

This approach work on any type of insect drawers and units.

c) Expected benefits

The physical setup is not expensive. Therefore, many systems could be installed in parallel to work overnight to produce the images of tens of drawers. In that sense, this is an alternative to conveyors. Human effort is probably smaller than operating conveyors.

c) Difficulties and limitations

Processing the huge numbers of images which will be produced will be expensive.

e) Recommendation

This approach should be tested in cooperation with an advanced robotics and machine vision lab.

4.6. Terahertz time-gated multispectral imaging

a) Features

Imagine reading a book without opening it, seeing ink through the paper… Terahertz technology has recently been introduced to airport security screening of passengers, and can visualise any objects hidden in pockets and elsewhere. Redo-Sanchez et al. (2015) describe how they extracted occluding textual content from a packed stack of paper pages down to nine pages without human supervision. This required time-gated terahertz scanning. Their application is close enough to our target application of reading stacked labels from pinned insects, and possibly through the wings of spread specimens.

For a time-gated use, the object that will be studied would need to be installed in motored environment, so that the layers would be imaged separately. This would probably require placing the pinned insect in a stand, and then moving the stand by a motor at millimetre steps across the range of stacked labels. Alternatively, the scanner could be moved accordingly.

b) Applicability

It is not yet known how the scan would react to insect wings and insect bodies, but labels can possibly be read.

c) Expected benefits

No need to handle the labels.

d) Difficulties and limitations

The resolution of what can be read is related to wavelength, which is about one millimetre. In insect labels the text is very small and may not be readable. Workarounds need to be investigated.

Motorised movement across the layers can take time, as in stack imaging. Again, this needs to be investigated.

e) Recommendation

This is a promising new technology that should be tried with a collaborating organisation that has the required equipment.

5. References

Blagoderov V, Smith V (2012) No specimen left behind: mass digitization of natural history collections. ZooKeys 209. https://zookeys.pensoft.net/browse_journal_issue_documents.php?issue_id=361

Brecko J , Mathys A (2016). Handbook of best practice and standards for 3D imaging of natural history specimens. SYNTHESIS3 Project Deliverable. Retrieved April 10, 2018: http://biowikifarm.net/v-mfn/3d-handbook/3d_Imaging_Handbook:Main_Page

Hereld M, Ferrier NJ, Agarwal N, Sierwald P (2017) Designing a high-throughput pipeline for digitizing pinned insects. 2017 IEEE 13th International Conference on e-Science (e-Science), Auckland, 2017, pp. 542-550. doi: 10.1109/eScience.2017. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8109193&isnumber=8109104

Holovachov O, Zatushevsky A, Shydlovsky I (2014) Whole-drawer imaging of entomological collections: Benefits, limitations and alternative applications. Journal of Conservation and Museum Studies. 12(1). http://doi.org/10.5334/jcms.1021218

Kroupa A, Pluta M, Schurian B, Glöcker F (2014) ZooSphere - A tool for automated spheric image capturing and interactive 3D visualization of biological collection objects. The Society for the Preservation of Natural History Collections annual conference, June 22-27, 2014, Cardiff, UK. https://www.researchgate.net/publication/268779382_ZooSphere_-_A_tool_for_automated_spheric_image_capturing_and_interactive_3D_visualization_of_biological_collection_objects

Kutner M (2014) Mission Not Impossible: Photographing 45,000 Bumblebees in 40 Days. https://www.smithsonianmag.com/smithsonian-institution/mission-not-impossible-photograph-thousands-bumblebees-40-days-180952211/#xJBZv7VJ3OoCw1C8.99

Nieva A, Rosin P, Sun X (2018) Specifications of tests on automated methods for mass 3D imaging. H2020-INFRADEV-2017-1 Project ICEDIG, Grant Agreement Number 777483. Milestone MS16 report, 11 p. Cardiff University.

Oever JP, Gofferje M (2014) From pilot to production: Large scale digitization project at Naturalis Biodiversity center. ZooKeys 209, 87-92. https://zookeys.pensoft.net/article/2921/

Redo-Sanchez A, Heshmat B, Aghasi A, Naqvi S, Zhang M, Romberg J, Raskar R (2015) Terahertz time-gated spectral imaging for content extraction through layered structures. Nature Communications 7, 12665. http://www.nature.com/articles/ncomms12665

Schmidt S, Balke M, Lafogler S (2012) DScan – a high-performance digital scanning system for entomological collections. ZooKeys 209, pp. 183-191. https://zookeys.pensoft.net/article/2913/

Tegelberg R, Mononen T, Saarenmaa H 2014. High-performance digitization of natural history collections: Automated imaging lines for herbarium and insect specimens. Taxon 63 (6) 1307-1313. http://www.ingentaconnect.com/content/iapt/tax/2014/00000063/00000006/art00010

Tegelberg R, Kahanpää J, Karppinen J, Mononen T, Wu Z, Saarenmaa H 2017. Mass digitization of individual pinned insects using conveyor-driven imaging. In: Hereld M (Editor) High throughput digitization for natural history collections. 2017 IEEE 13th International Conference on e-Science (e-Science 2017). Auckland, New Zealand, 24-27 October 2017. 5 p. https://ieeexplore.ieee.org/document/8109190/