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Towards the Automatic Extraction and Annotation of Information Elements from Handwriting Notes

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***Abstract*— Despite the information technologies solutions available in the market, paper-based notes are still used in academic and research environments. The unstructured nature of handwriting paper-based notes entails several challenges for the automatic extraction of information elements such as figures, tables, and equations. In this work two studies are presented: the first one explores the working practices for recording notes and meaningful research data of a fiber optic sensors research group. The second study is an extension of a previously reported work, which involves users in the process of information element extraction by adding a step where they manually outline the research information elements on the paper notes. The extension of this study includes the evaluation of a low-fidelity prototype design proposed for a laboratory notebook application. We present an analysis of the results and the feedback obtained that will inform the development of an electronic notebook for fiber optics sensors research.**

Keywords— electronic notebook; information elements; research notes; prototype evaluation; fiber optic sensor;

I. Introduction

Paper notebooks are still a popular means for recording relevant information in research and academic environments. A laboratory notebook is an instrument where research experiments, associated data, annotations and results are registered. This should be a means to support research reproducibility and traceability. Despite of the development of new technology and software solutions for electronic (laboratory) notebooks, users still tend to use pen and paper for recording handwriting notes given their "natural" interface and ease of use [1]. For instance, it is faster to draw sketches and make annotations on paper without the limitations imposed by other interfaces. Paper-based notes may offer a more natural user experience for registering data but the limitations on information retrieval are obvious.

Handwriting notes are characterized by their flexible structure, where information elements (IE) such as text, tables, drawings, notes, equations, etc., could be defined in different colors, orientations, and sizes. However, the use of handwriting notes also brings some drawbacks for accessing and retrieving specific pieces of information in the long run.

In research scenarios it is important to preserve handwriting paper-based notes and specific information elements to make them accessible. Transcription of handwriting notes to generate electronic ones could be made using Optical Character Recognition (OCR) technology but the automatic identification, extraction, and annotation of information elements is still a challenge for the research community.

Electronic Laboratory Notebooks (ELN) offer the possibility to include enriched and linked data such as text, images, web and resource links, and other forms of electronic information. ELNs are now available as software solutions with multiple device interfaces, for instance as desktop, web, and mobile applications. ELNs have been reported in various research scenarios including biology and chemistry [2].

There are different barriers for adopting electronic notebooks in research environments. For instance, research institutions may have policies for registering experimental and research data using paper-based evidence for legal purposes [2]. Furthermore, researchers may resist adopting ELN's and replacing paper-based notebooks if they have to change their working practices [1]. The NeuroHub project [3] reported the use of smartpens for recording laboratory notes, while preserving the working practice to register their notes on paper, with one additional step for loading the notes saved in the smartpen onto the NeuroHub system for their preservation.

Many ELN off-the-shelf software solutions are available. In [2] the authors present a review of ELN's that are grouped in 5 categories based on the primary market audience: Research and Development (R&D), Biology, Chemistry, and support for Quality Assurance and Quality Control (QA/QC). ELN´s used in research environments include specific capabilities that provide a better user experience, for instance, a support to specific scientific formats [2].

This work describes the work conducted with Fiber Optic Sensor Researchers (FOSRs) and computer science students [4]. Two studies are presented. First, a study was conducted to understand the working practices of FOSRs regarding the registration, preservation, and access to information and notes taken during their research practices. The second study was focused on analyzing a proposed approach for assisting the extraction and annotation of IEs from paper-based handwriting notes using smartpens as part of the workflow. This study is an extension of the work reported in [4] by including the evaluation of a low-fidelity prototype developed.

II. LITERATURE REVIEW

Despite of the variety of ELN solutions available in the market [1, 2] there is still some resistance and barriers to their adoption. There are some works aiming at understanding better the needs and requirements for developing a ELN that satisfy the user needs, while others focus on providing innovative user interfaces to facilitate their work and improve their user experience.

In [5] the authors report a study conducted with experimental physicists researchers to understand which aspects were intervening in the adoption of electronic laboratory notebooks. The authors carried out a series of interviews, to learn about researchers' working practices at the laboratory, and conducted future casting workshops. During the workshops participants envisioned how technology could be embedded in their working environment in the future and without imposing any technological limitation. In the conclusions to their work, the authors propose a list of requirements to be considered in the development of future ELNs.

There are some other approaches to bring together paper and electronic notebooks to offer a better user experience. An augmented laboratory notebook that brings together physical and electronic information is reported in [6]. The authors described three prototypes that were developed using participatory design carried out with biologists, managers, and archivists. Their final prototype called the *a-book* followed a document-centered approach comprising a paper notebook, a graphics tablet, a handheld personal digital assistant (PDA), inking and non-inking pens. The architecture of this prototype included a three-layer information model: the paper page layer, the ink layer with the handwriting, and the annotation layer. In these prototypes, underlying and boxing pieces of information were used as user interaction techniques. Underlying was used for indicating when a text should be considered as a URL, and information elements were boxed to indicate their raw preservation. On the other hand, boxing was used as a user interaction technique to capture regions of interest of images that could be labeled and linked to other pages within the notebook.

Another proposal to bring together paper and electronic notebooks was presented in [7] where the authors report Prism, a hybrid laboratory notebook as a technology probe [8]. Prism evolved from a desktop application to an online tool to support collaborative work and included functionality to support paper and electronic notebooks. Prism also provided functionality to embed electronic resources such as emails, websites, and documents.

III. STUDY 1: UNDERSTANDING WORKING PRACTICES

In this study the working practices of FOSRs for recording, preserving, and retrieving relevant information of experimental data.

A. Participants

In this study 6 FOSRs of two departments situated in two cities around 60 kms apart were interviewed. These researchers have a record of collaborative work in multiple projects and research papers. All researchers hold research professor positions at the University.

B. Requirement Elicitation Method

Researchers were interviewed at their offices or laboratories. Two series of interviews were carried out. First, a semi-structured interview was conducted to learn more about their working practices and struggles. During these interviews researchers were asked questions about: a) working practices for registering associated data and information of their research, b) data and information they normally record in each experiment, c) tools that are used to assist the process of recording, preserving, and accessing data, and d) use of logbooks to record meaningful data about their research and experiments. After analyzing their responses, a series of structured interviews were conducted to clarify some of their answers and to explore some insights shared by their colleagues. Sessions were recorded on pencasts using a LiveScribe Echo smartpen.

C. Results

The responses of the FOSRs were analyzed

a) *Working practices for registering research related data and information*: The FOSRs interviewed carry out experimental research and the use of laboratory facilities is fundamental part of their workflow. Information and data generated by students and research assistants are generally shared through email. Researchers at the University are not obliged to use (paper-based) research logbooks, since there is no institutional requirement for doing so.

b) *Data and information are recorded in each experiment.* Data generated during the research process can be produced during the generation of the idea, parameters, and characteristics of the fabrication of the sensor, the definition of the experimental setup, the measurement and characterization of the sensor, the analysis of the measurement data, and the results obtained.

c) *Different tools are used to assist the process of recording, preserving, and accessing data*. For manually registered data, the reported tools used by researchers range from paper-based notes (notebooks, blank sheets of paper, post-its, etc.) to software solutions such as MS Word, MS Excel, Wordpad, and Sticky Notes.

d) *Use of logbooks to make notes and record data about their research and experiments.* Researchers like to register information in the computer for preserving information, making comments, providing information files to new members of the team. They appreciate to be able to record information as they prefer.

Regarding handwriting paper-based notes, some researchers appreciate the natural interface of writing and drawing on paper, "it is fast to draw diagrams and sketches". Some of them highlighted that in some cases there are some issues for understanding handwriting notes, "only the person that writes it down understands it". Another disadvantage of paper-based notes is that these are prone to be lost. Thus, some of them transcribe paper-based notes in electronic notes but indicated that this is time consuming and that there are some pieces of information that cannot be easily transcribed such as diagrams and sketches.

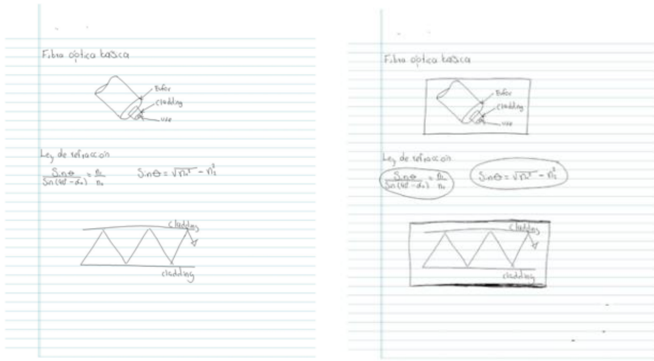
Working practices for recording and managing experimental data produced by students. Researchers work with students at the laboratory, both in academic and research activities. In some cases, students register notes and data in their own notebooks, while in other cases the researcher and the students work with a shared notebook. The information and notes captured by the students is shared with the researchers by sending via email the associated files, handing over a USB stick with the measurement data files, handing over paper-based handwriting notes, or uploading the files and information into a cloud shared storage, etc. Researchers check the notes sent and provide feedback about the experiment also either via email or in a face-to-face meeting.

Suggestions were made for creating a standardized version of a logbook. However, FOSRs thought it was difficult to pre-define the order for capturing parameters and data. Another suggestion was to provide an automatic process for transcribing and backing up handwriting notes with immediate access to the data and to include an index and a page number to each note to locate information in an easier and faster way. For researchers is important to access old logbooks so they can repeat and compare experiments if necessary. In their view, a logbook is obsolete only if either someone abandons the area of research or retires. Some researchers use (paper-based) notes from the early stages of their research process, including the investigation of state of the art.

These results indicate that FOSRs were aware of the advantages and disadvantages of handwriting notes vs electronic notebooks. In the next study, the preservation of raw data while transcribing handwriting notes into electronic ones is explored.

IV. Study 2: Evaluation of User Interaction Proposal for Extraction and Annotation

Researchers need to preserve notes in a digital format where they can have access to specific data. Thus, it is necessary not only to identify information at the page level but also to identify specific information elements within a page. In this context, we call information elements (IE) to figures such as diagrams, sketches, etc., tables, and equations that are not easily detected and transcribed in electronic notes. In Figure 1, a note created for illustration purposes is shown in (a) and the same note with IEs, such as diagrams and equations, enclosed in rectangles and ellipses is shown in (b).



(a) (b)

Fig. 1. Example of a) a paper-based note b) information elements manually outlined. Notes created for illustration purposes.

The transcription and beautification of these elements is a challenge for the research community. In [9] the performance of Optical Character Recognition (OCR) tools was evaluated for extracting IEs in handwriting notes with no good results.

In this study, an approach for automatically extracting and annotating IEs on paper-based handwriting notes is presented as reported in [4]. The users enclose information elements of interest using geometrical figures drawn by hand on the paper notes. A geometric figure is associated to an IE, so that when the image is loaded into the system it can automatically be annotated with the associated category (figure, table, equation, etc.). In this way, raw IEs can be annotated and retrieved, allowing the user the possibility to preserve and access them as required.

One of the aims of the study as reported in [4] was to understand if marking the notes with these figures evokes any (negative) feelings in users. Furthermore, it was aimed at understanding the technical challenges associated with this approach. The work reported in [4] is extended in this study by presenting the evaluation of a low fidelity prototype proposal with students and researchers.

The proposed workflow considers that notes are generated using the Echo Smartpen and the user is required to draw geometric figures to enclose the IEs of interest. Then, the images generated are downloaded and exported as images using the Echo Desktop Application, which is the application used to manage the notes generated with the Echo Smartpen device. These images are then uploaded into the prototype and a process to detect the geometric figures is carried out. As a result, the extracted image regions are automatically annotated as figures, tables, equations, etc. according to the predefined association between geometric figure and IE. For instance, in Figure 1, rectangles were associated to diagrams and ellipses were associated to equations. The user can add additional labels to enrich the description of the IE. Information about the IE location and labels are stored in a database. Then, the user can search for notes and IEs using the labels defined as searching criteria. Further details about this prototype are presented in the next section.

A. Methodology

The development of this study as reported in [4] was carried out using an interactive design process ISO 9241-210:2010 [10] and the ISO/IEC 25040 [11] for the evaluation step. An evaluation of the proposed user interaction and the design of a low fidelity prototype is carried out.

B. Low Fidelity Prototype

A low fidelity prototype was developed to show the functionality for extraction and annotation of the intended IEs, to obtain feedback about the prototype, and to inform the development of an electronic (laboratory) notebook. The requirements considered in this implementation, as reported in [4], included the recognition of two geometric figures: rectangles and ellipses. These would be associated to two IEs and the association is subject of evaluation during the study. Then, the tool should recognize rectangles (FRQ-01) and ellipses (FRQ-02) in an image. It needs to be considered that the images generated from Livescribe notes can include a ruled or grid paper. Then, the requirements include recognizing rectangles (FRQ-03) and ellipses (FRQ-04) drawn on Livescribe dot paper. The sketch of the prototype is shown in Figure 2. A paper-based version of this was shown to the participants during the experimental session.

A proof of concept for extracting the geometric figures was developed using Visual C#, Windows Presentation Foundation (WPF), and EMGUCV.NET [12] the OpenCV wrapper for .NET. The algorithm implemented for extracting the geometric figures from the images, as described in [4], includes a first step for improving the image quality, that is pre-processing the images for reducing noise and applying operations eliminate the background (paper pattern) and then applying OpenCV contour features [13]. The algorithm had a very good performance with synthetic geometric figures and the aim was to check its performance with the geometric figures drawn by hand by the participants.

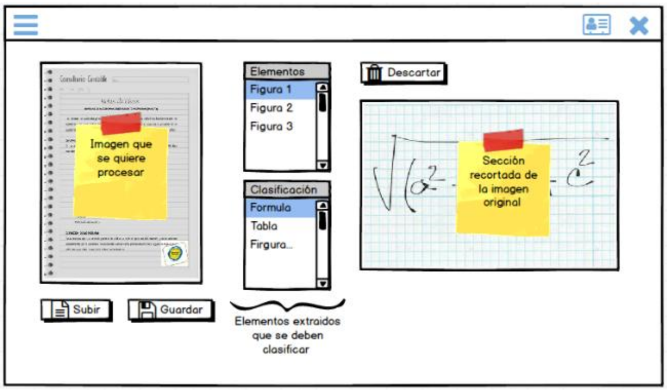


Fig. 2. Paper-based prototype.

C. Experimental session

During this session 30 participants, that included undergraduate students and professors, carried out a series of activities enclosing different IEs included in two notes previously generated for testing purposes as described in [4]. Furthermore, a paper-based version of the low fidelity prototype was presented to each participant, describing the proposed functionality and workflow. Finally, participants answered a questionnaire, as reported in [4], for assessing their experience and their feedback regarding the prototype presented. The questions, that will be addressed in this study are Q10-Q15.

D. Results

In this section we present the results of the experimental session. First, the responses to the questions associated with the evaluation of the low-fi prototype.

- Q10. Do you think this application would be useful to you? why? 97% of the participants indicated the proposed application would be useful for them as this would help them to organize the information, to facilitate notes transcription in a digital format, and to save time, among others.
- Q11. Do you think that extracting equations and diagrams from your notes would be useful? Why? 97% of the participants thought that extracting figures and equations would be useful, as this would facilitate the design of teaching material, save time to share their results to the research group for their analysis.
- Q12. Do you think images, buttons, and text are well organized in the Low-Fi prototype interface? 97% of the participants thought the user interface elements such as images, buttons, and text were well organized in the user interface presented.
- Q13. Would you change or remove something within the user interface? If so, what would you change? 93% would not change the user interface, while the rest thought the design was “invasive” and colorful, which was distracting for them.
- Q14. Do you consider that it is more useful that the application classifies the images for you? 93% of the participants thought it was more useful for the application to classify the IEs for them.
- Q15. Do you think that the icons in the interface are associated with their functions? 77% of the participants thought the icons used in the user interface were well associated with their function, while the other 23% thought that most of them were well associated.

VI. DISCUSSION

The studies presented provide conception and evolution of the proposal aimed at extracting and annotating individual elements within a note and to include smartpens in the research workflow to assist the note digitalization.

The proposal for users to manually mark IEs in the notes using geometric figures was well accepted by the participants. FOSRs suggested to include the same functionality to mark IEs in the system. This would provide a more general functionality for pictures of (handwriting) notes already available in digital format.

FOSRs made emphasis on extracting the information contained within the IEs for further data processing including tables of measurement data. The link to MS Excel for importing and exporting data and graphs was also suggested. Furthermore, it would be ideal to automatically generate these tables of measurements by creating an interface with the measurement devices so that the tables would not need to be registered on paper at all.

The importance of recording time stamps was highlighted multiple occasions. Therefore, it is important not only record this data but also to make it visible and use as a search criterion within the system.

The use of handwriting paper-based noted is still a popular practice not only in the research but also in learning environments. Handwriting not only takes place on paper but also on (white) boards placed in labs, offices, and classrooms. A common practice for recording board-notes is taking a picture of it. However, if the picture is not downloaded and properly organized its information can be lost. Therefore, the workflow defined in our approach should not be limited to using smartpens. Given that notes are recorded in images this workflow should be generalized to include handwriting notes captured in images. Therefore, the application should also include the functionality to perform OCR on the images loaded.

Sharing information was an aspect also highlighted. Monitoring experimental steps and results is also needed. Therefore, the architecture of the solution should include functionality for sharing information at the logbook, note, and IE level.

VII. CONCLUSIONS AND FUTURE WORK

In this work we have presented three studies to provide a tool to FOSRs to assist their working research practices. It was observed that researchers also would like to extend the use of this tool in their teaching environment. The proposal for using smartpens in their workflow was well accepted, however, it needs to be extended to include also images of handwriting notes obtained with other devices.

The adoption of the electronic (laboratory) note solution is one of the main challenges. As part of the future work, we are developing a solution that can be embedded within the working practices of the researchers and students.

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