A Framework for Automated Multiple-Choice Exam Scoring with Digital Image and Assorted Processing using Readily Available Software

Jose Antonio Catalan
De La Salle University
jose.antonio.catalan@dlsu.edu.ph

Abstract: **Multiple-choice-question (MCQ) exams are widely used by educators for assessing the academic performance of their students. These exams have the benefit of allowing automated scoring. Although online platforms are available for implementing these exams with automation, there are valid reasons for not adopting them and still make use of printed answer sheets. While optical mark reader machines are available for automatically scoring hand-marked answers, they are generally expensive to acquire and operate. The use of scanners and digital cameras with image processing software offer a cheaper alternative. This paper presents a framework based on the latter approach using readily available software. This implementation approach, instead of a singular software solution, offers greater flexibility and allows the user to expand functionality. The framework uses a combination of Octave scripts and spreadsheet software to perform optical mark reading and automatic scoring. The framework is able to deliver high scoring accuracy and significantly increases the productivity of teachers. It also improves the accessibility to automatic scoring of MCQs.**

Key Words: multiple-choice quiz; automated scoring; optical mark reader

1. INTRODUCTION

Educators have long used multiple-choice questions (MCQ) in assessing student performance. Designed properly, MCQ exams can be very effective and can be scored rapidly allowing quick feedback to students. The traditional way to do these exams require hand-marked answers. A modern way to implement these exams is to execute them online which is amenable to a high degree of scoring automation. However, many teachers still prefer the traditional approach and stay away from online exams for various reasons. Scoring for these exams can be done automatically using machines that use Optical Mark Readers (OMR) with specially designed answer sheets. Acquisition and operation of these machines, however, can be very expensive.

Alternatives to using OMR have been developed. Approaches that still use hand-marked answers invariably make use of digital image processing techniques and applied in a local computing machine (China et. al 2016; Patuoule et. al 2016; Zampirolli et. al 2013; Tavana et. al 2016) or online (OMR Sheet Scanner Software, 2016; GradeCam 2017). The answer sheets first undergo image registration using scanners or cameras. The image data are then processed using software to to recognize the hand-marked answers. The commercial

systems have limitations for free use and require payment of fees to allow access to full functionality. The free online systems may not be to everyone's liking since exam data will have to be uploaded to a server owned by a third party. Freely available software for local machine use do not offer much flexibility and many are not bug-free. The software used in most of the reported work in the literature are not readily available to the public. This makes it difficult for users to add functionality.

2. PROPOSED FRAMEWORK

The proposed framework for executing and scoring MCQ exams includes the following components: 1) custom printed answer sheet, 2) scanner or camera, 3) Octave scripts, 4) Microsoft Excel or compatible spreadsheet software. 5) Email software with mail merge function.

The answer sheet is designed using Microsoft Word to accommodate 120 standard bubble placeholders for the answers. Markers are incorporated into the sheet to aid in the automatic recognition of answers. An answer sheet template is printed using regular inkjet or laser printers on regular white bond paper. This can be reproduced using standard photocopying machines with clean output.

Octave is free software available for Microsoft Windows, Linux and Mac/OS that is mostly compatible with Matlab, a numerical computing software. The Octave scripts were developed by the proponent to apply digital image processing to perform the main task of automatically recognizing the answers of the students as reflected in the answer sheets.

A spreadsheet is used to collate the exam data and perform the actual scoring. This is the preferred approach for scoring to using answer keys that are formatted the same way as the answer sheet and compared with those of the students. This way scoring can be made more flexible.

Mail merge email sending allows forwarding of results to individual students to keep the information private. This is an alternative to the common practice of posting a list of students and just using student numbers to implement a semblance of anonymity.

Unlike many of the existing work which uses singular software implementations, this work focuses on a framework that make use of several readily
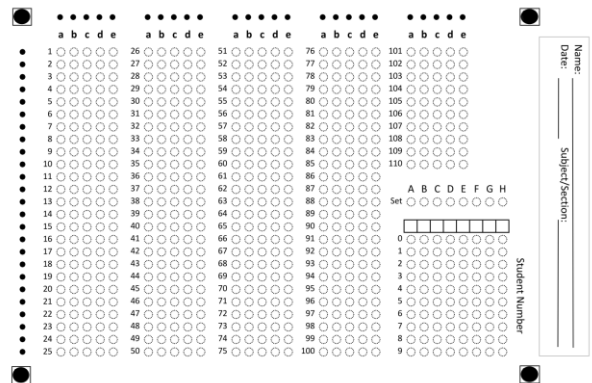

Fig. 1. Answer Sheet

available software, making it highly modular. One auxiliary motivation for this approach is to allow knowledgeable users to expand or tweak some functionality at multiple software component level. However, it is recognized that it may be difficult to make the framework implementation completely fool-proof for novice users.

The proposed workflow involves the following:
1. Print custom answer sheets using inkjet or laser printers.
2. Reproduce the answer sheets using B/W photocopiers.
3. Execute the exam and collect the answer sheets.
4. Scan the answer sheets using a flatbed scanner, preferably with an automatic document feeder (ADF) and save as individual images.
5. The images are processed using Octave scripts and exam data is exported to a comma-delimited file.
6. The exam data from the Octave scripts are imported into a spreadsheet template together with the answer data for scoring.
7. Send results with annotated (with markers) scanned sheets to the students using mail merge emails (ex. Thunderbird).

2.1 Answer Sheet

The answer sheet template used is shown in Fig. 1. Two sheets can be printed on one page of an ordinary typewriting paper. The sheet has the following elements: 1) Answers section that can accommodate up to 120 exam items, 2) Student number section, 3) Handwritten information section, 4) Alignment markers.

The formats for elements 1 to 3 were made similar to those used in equivalent elements in the commercial OMR typically encountered by students in final exams. The template can be reproduced using black and white photocopiers or similar methods.

Each exam item has a preset number of five choices. This is the most common set-up for most multiple choice exams implemented by the author's academic unit.

There are four alignment markers one on each corner. The location of these markers are detected and used as a reference for the location of other relevant features of the answer sheet.

2.2 OMR Technique

The framework presented in this paper employs an OMR process to recognize answers without integrated scoring intelligence. Scoring is done in a separate process. The answers are recognized from the answer sheet using the following steps:

1. The answer sheets are grayscale-scanned (image registration) at a resolution of 300 dpi and placed into a common directory.
2. The scanner output images are batch-cropped to cover half a page if the scanner output is full-page.
3. The images are converted to black and white.
4. The location of the alignment markers are detected automatically using template matching against the reference marker image. The search is done one quadrant at a time.
5. Two alignment markers are used to correct any unwanted rotation during scanning. A sample is provided in Fig. 3.
6. After rotation correction, three markers are used to determine the reference location and size of the relevant features of the answer sheet.
7. Using the known number of exam items, the image areas of all five choices of each item are analysed using template matching with a reference image for a marked item. If a match score is higher than a preset level, the choice is considered to be marked. The preset level was obtained empirically to minimize false detection. Prior to matching the projected locations of the choice image objects are pre-calculated using the detected locations of the alignment markers. Scaling is built into this process.
8. The student number is also recognized using a similar method for the detection of marked exam item choices.
9. Images of the answer sheets are annotated by superimposing markers that match the projected locations of the answer placeholders and the detected marked answers. A sample is provided in Fig. 2.
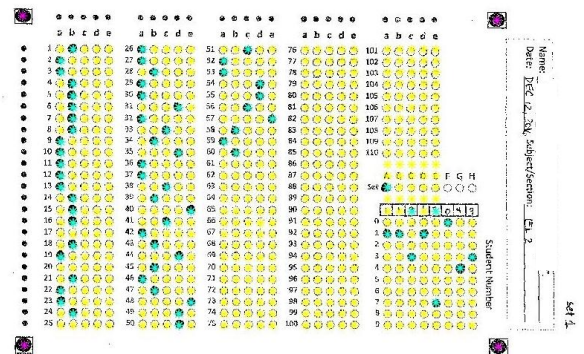10. The marked status of the choices for each of all the exam items, and the student numbers are

Fig. 2. Sample of annotated answer sheet.

written into a comma-delimited file.

Steps 2 to 10 were implemented using Octave.

The Octave-based mark recognition method described above can be considered as a module. Other scripts to perform the same thing can be developed and added as on option for this step in the workflow.

2.3 Automatic Scoring

In many OMR-based scoring systems, the correct answers are presented to the system as an answer sheet with correct answers entered. The framework presented in this paper prescribes the use of a spreadsheet for specifying the correct answers and performing the scoring. Scoring in this case is done using formulas. The output of the previous OMR process is compared to the correct answers by formulas. Scores are then calculated.

The scoring approach used here allows greater flexibility and functionality. It would be straightforward to modify the scoring spreadsheet so that positive or negative weights can be added for either correct or incorrect answers. Formulas can also be set up to allow scoring with multiple correct answers. This can be combined with varying weights for the possible answers. Using the same spreadsheet

A spreadsheet template has been used to make the implementation of scoring easier. Although not yet applied in the current work, the generation of templates can be automated by scripting.

2.4 Student Feedback Mechanism

The framework includes a mechanism to provide feedback to students using information from the scoring process. The spreadsheet format used is amenable to sending of the results to students individually using mail merge functionality of email client software. Thunderbird has been used in this work. The answer sheet scans annotated by the OMR process can also be attached together with the results during mail merge. Sending the annotated images allow students to review the OMR output to check if their answers have been registered correctly. This is important because of potential sources of errors due to external factors such as the quality of reproduction of the answer sheets, creasing and other imperfections.

3. APPLYING THE FRAMEWORK

The framework presented has been applied to multiple courses across a span of three years. It has been used for true or false and multiple-choice exam items on quizzes and final exams. This is equivalent to applying the framework on a total about 800 answer sheets for exams in 8 courses.

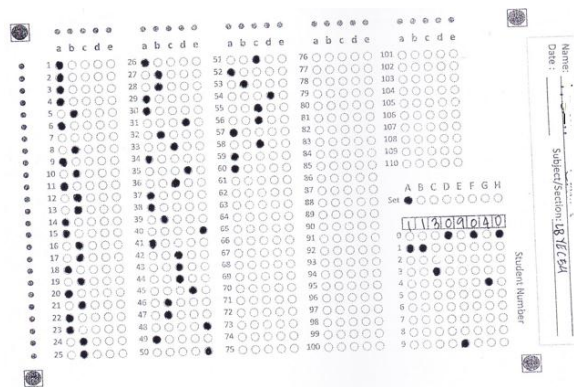The current implementation of the framework components does not optimize on the

Fig. 3. Sample of scanned image with rotation.

speed of the OMR process but prioritizes accuracy. Scanning was done using the Canon MX430 printer with automatic document feeder (ADF). A limited number of scoring spreadsheet templates have been developed but it is straightforward to add more.

The use of the spreadsheet format also makes it easy for the author to integrate the scoring framework with another work involving spreadsheet-based quiz randomizer and questionnaire generator.

3. RESULTS AND DISCUSSION

The scoring accuracy is high with only 10 recorded errors out of 800 sheets. These errors were attributed to defects in printing and paper handling during scanning.

Scanning of the answer sheets took 5-7 seconds per sheet. This is very slow compared to the speed of hardware-based OMR systems. However, since the scanning is done through an ADF, the user can still be productive with other tasks while waiting for the scanning to complete. This scanning process can work with any scanner but one with an ADF function is best to use.

The Octave OMR scripts, while currently in non-optimized form, can process each answer sheet with 120 items in 1 minute and 8 seconds. While this is also slow compared to the performance of hardware-based OMRs, it is a lot better than manually checking the answer sheets. Many options

are available to speed up the performance for future work.

Not everyone will find the current implementation of the framework easy to use as it was not included in the initial priorities of the work. It assumes that the user is well-versed with formula-based processing with MS Exel or compatible software and running scripts on Octave. However, many aspects of the framework can be readily enhanced to improve ease of use and processing speed.

The reduced scoring effort with the use of the framework allowed the author to add MCQ assessment in grading system items that do not customarily include it because of the additional effort required. Furthermore, the framework made it easy to analyse the exam results for a variety of purposes. This may include identifying items that most students were not able to answer. This result might be indicative of a major deficiency in the instructional methods or might allow identification of errors in the formulation of exam items.

One of the major benefits of using the framework is it can free teachers from reliance on institutionally provided resources. Many of the components required are well within the reach of many teachers.

4. CONCLUSIONS

In this paper, a framework for automatically scoring multiple-choice exams was presented. It has been demonstrated to work in several courses with high accuracy. The use of the system resulted to time savings allowing the author to incorporate MCQ exams to good effect in course assessment items where these are not customarily included. It also allows more information to be fed back to the students and has the benefit of allowing flexibility at each stage. The proposed multi-stage, multi-software approach offers an alternative to existing systems that do not have all the features an educator may need.

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