Multimodal Selfies: Designing a Multimodal Recording Device for Students in Traditional Classrooms

Federico Domínguez
Escuela Superior Politécnica del Litoral
Vía Perimetral Km. 30.5
Guayaquil, Ecuador
fexadomi@espol.edu.ec

Vanessa Echeverría
Escuela Superior Politécnica del Litoral
Vía Perimetral Km. 30.5
Guayaquil, Ecuador
vecheverria@cti.espol.edu.ec

Katherine Chiluiza
Escuela Superior Politécnica del Litoral
Vía Perimetral Km. 30.5
Guayaquil, Ecuador
kchilui@espol.edu.ec

Xavier Ochoa
Escuela Superior Politécnica del Litoral
Vía Perimetral Km. 30.5
Guayaquil, Ecuador
xavier@cti.espol.edu.ec

ABSTRACT

The traditional recording of student interaction in classrooms has raised privacy concerns in both students and academics. However, the same students are happy to share their daily lives through social media. Perception of data ownership is the key factor in this paradox. This article proposes the design of a personal Multimodal Recording Device (MRD) that could capture the actions of its owner during lectures. The MRD would be able to capture close-range video, audio, writing, and other environmental signals. Differently from traditional centralized recording systems, students would have control over their own recorded data. They could decide to share their information in exchange of access to the recordings of the instructor, notes form their classmates, and analysis of, for example, their attention performance. By sharing their data, students participate in the co-creation of enhanced and synchronized course notes that will benefit all the participating students. This work presents details about how such a device could be build from available components. This work also discusses and evaluates the design of such device, including its foreseeable costs, scalability, flexibility, intrusiveness and recording quality.

Categories and Subject Descriptors

K.3.1 [**Computing Milieux**]: Computers and Education-Computer Uses in Education

Keywords

Multimodal Recording; Learning Analytics; Recording Quality; Data Privacy

ICMI 2015, November 9–13, 2015, Seattle, WA, USA.

ACM 978-1-4503-3912-4/15/11 ...$15.00.
DOI: http://dx.doi.org/10.1145/2818346.2830606 .

1. INTRODUCTION

The first law of technology according to Kranzberg [19] is that it is neither good nor bad, nor is it neutral. Learning Analytics, seen as an Educational Technology, also follows this law. The act of collecting data from learning environments automatically creates a balance of power between students, instructor and the educational institution [32]. While references to *Big Brother* or *Foucault's Panopticon* can be seen as extreme comparisons for the Learning Analytics practice, there are real privacy concerns that need to be addressed before implementing data-collection schemes [24]: How to maintain transparency about the use of data, who owns and controls data, who has access to (different parts of) data and how to account and assess their good use. While all these privacy dimensions are important, ownership of data is the dimension most influenced by the recording strategy. An example of the impact of data collection in the perception of privacy, the so called privacy paradox [18], is the following: the difference in reaction when a stranger takes a photo of an individual in a public space and publishes it on the Internet, versus when an individual takes a "selfie" in the same spot and uploads it to a social network, such as Twitter. The end result is the same, the picture is now public for everyone to see. However, in the first scenario, the individual could feel that its privacy has been violated, but in the second scenario, the same person could even be happy to receive comments from strangers about the picture. All other things being equal, who does the recording and who controls what and when is recorded has a direct influence on the perception of ownership of data and the perception of privacy invasion.

One of the learning environments where recordings are especially problematic from a privacy viewpoint is the traditional classroom. Differently from virtual environments or specialized settings, there is the expectation of privacy in the classroom, as recording devices have never been part of it. This problematic feature and the ethical aspects of video-recording lectures have sparked debate among educational researchers and remain controversial to these days [8] [9] [29].

Despite these dilemmas, researchers and participants of studies have pointed out the positive side of video recording in natural settings, such as classrooms [12]. The following privacy protecting solutions to gather data in classroom settings are a point of reference [13]: manual annotation, no video (least invasive); fully automated digital video capture, data is gathered at all times without teacher intervention, manual or automatic indexing is used; fully automated capture with a location-based filter, video captures individuals interacting with specific objects of interest, surrounding environment is blurred, the videos are manually or automatically indexed; fully automated capture with a subject-based filter, space around the subject remains clear while anything else is blurred; and, selective archiving of captured video, everything is captured at all times, but the archiving procedure requires manual intervention. The usage of such recordings are often related to explorative/ experimental objectives, where subjects are prompted to use artifacts, or engaged in situations or environments where they perform some activities, while data are gathered for future analyses [2]. These scenarios are monitored and set-up before the subjects participate in the experiments and teachers and learners might not be aware of the recording that takes place or the related equipment. The same applies for initiatives such as the MIT OpenCourseWare (OCW) project, where they share audio/video recordings and supporting class material. Projects like this are very popular and have generated public awareness about open content and research about its impact on informal education [33] [30] [4]. In these initiatives, the focus of the videos was usually the lecturer and her/his writing on the blackboard or the slides, not the students. The video camera is always located at the back of the classroom and the lecturer's voice was captured via a lavalier microphone. Nowadays, with the availability of mobile phones, tablets and similar devices, innovative approaches that are built-upon their ubiquitous nature have appeared. These approaches allow students to: add value to class notes shared by their lecturers and learn more from them [2], do crowd-sourcing in learning [6] [7], support teachers in their teaching [3], and many more. For instance, in [17], students can video-record themselves expressing their opinions about a task designed by their teachers. This happens in a private platform where teachers and students can interact and see what others post.

The approach of this study is to give students the opportunity to video-record their interactions, poses, emotions and notes by means of a Multimodal Recording Device (MRD). This device sits on top of the student's desk while collecting audio, video and the notes the student takes while attending a lecture. The same set of data would be gathered by other students that would like to share their interactions during and after the class. Meanwhile a video camera is recording the lecture, focusing on the lecture and the notes the instructor makes in the whiteboard or the slides. After the lecture is finished, the annotations and instructor's slides synchronize with the students' notes; thus, everyone that attended the lecture gets an enhanced set of notes and lectures. The sharing of such information is optional from the side of the students; however, all the students would have access to the recorded lecture but only those that shared their recordings would gain access to the enhanced set of information.

This paper is structured as follows: first, a review of related work is presented; next, the design of the proposed device is described, including a section about the potential applications of such device for the students, the instructors, the institutions and educational researchers; following, a set of criteria are used to analyze the proposed design. Finally, the paper closes with conclusions and next steps to implement and evaluate the MRD.

2. RELATED WORK

Recording a lecture in a traditional classroom is an activity that learners have been doing for several purposes. These recordings imply the use of one or multiple devices, dedicated to the recording of: teacher interactions, students' attention and interventions (through video cameras, microphones, digital pens and multitouch surfaces).

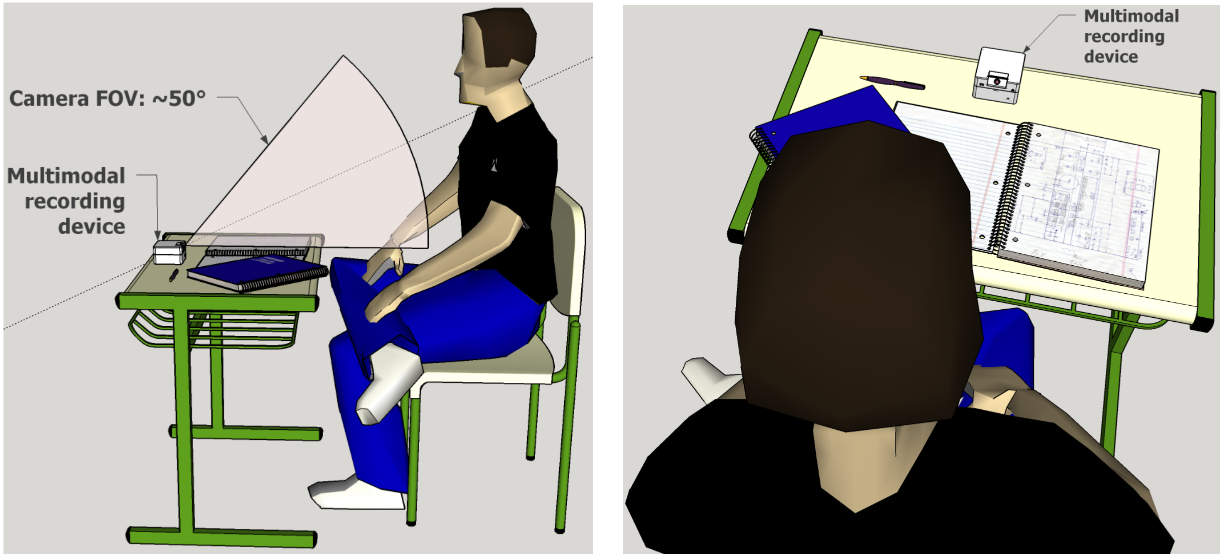
As mentioned in the introduction, there has been a plethora of studies where educational researchers have used video recording of lectures to gain insight on student behavior. However, only a handful of studies approaches the problem from a learning analytics perspective, that is, recording the lecture to automatically analyze the students' behavior and providing immediate feedback to the participants. These studies usually focused on the determination of the level of student attention [28] [27] [25]. The multimodal recording setting consists in a set of cameras located in the classroom to capture the teacher's interactions as well as the students' attention. Automatic descriptors, such as slide duration or question and answer duration, can be extracted from the teacher's video recordings; whereas the students' level of attention can be determined by quantifying the student's gaze direction [25] or tracking and recognizing individual student interactions [22]. Additional resources such as questionnaires and interviews from students, and an eye tracker for the teacher, are used to perform a holistic analysis of what is actually happening in the classroom [26].

Another methodology to capture the students' interaction is through the use of multi-tabletop systems (MTS). These systems have been used for supporting different stages of collaboration in group work activities [5] and for planning learning activities on the teacher's side [23] [16]. They are capable of collecting the students' writing and interaction activities with learning objects through finger or pen-based input methods [11]. More sophisticated MTS can also understand voice commands to interact with the system [14].

The solution presented in this paper differs from these works in two main points: 1) It is not based on a centralized recording setting. The distributed approach is more flexible and highly reduces privacy concerns, and 2) It is multimodal in nature, enabling a more holistic analysis of the behavior than just recording unimodal signals.

3. DESIGN

Recording a traditional classroom has usually two components: 1) capturing the actions of the instructor and the materials he or she is presenting and 2) capturing the actions and artifacts produced by the students. There are several successful designs for the first component, for example Galicaster [10], a hardware solution to record lectures and Project Matterhorn [15], a full open source suite of software to capture, edit and distribute those lectures. While these systems have not been used for research, their recordings can be easily re-purposed to analyze the behavior of the teacher in the classroom. On the other hand, as mentioned in the Related Work section, there has been very little research on how to produce automatic recordings of the students and



(a) MRD in the classroom (b) MRD from the student's point of view

Figure 1: The Multimodal Recording Device (MRD) is a relatively compact appliance designed to sit unnoticed on top of a student's desk. It collects video, audio, environmental parameters and notes during class. Its video camera aims at the student's head and torso.

their artifacts. The design proposed in this work, a MRD, focuses on this second component.

3.1 Design Principles

The process to design a solution to record the students during lectures was guided by the following principles:

- Privacy should be respected. The system should be owned and operated by the student and the control and ownership of the data should remain in the possession of the student that generated it. The student will always have the control of the device and can decide at any time during the lecture to start or stop recording.
- The recording device should be small and cheap enough to be taken from classroom to classroom. It should be a portable device that connects to their cellphones or laptops and should not cost more than a low-end smartphone.
- The recording device should provide a clear value to the student that uses it. Sharing the recordings produced by the device should provide some incentive to the student. Even if not shared, the recording devices should be useful *per-se*.
- It should record as many modes (video, audio, writing, temperature, movement) as feasible for future analysis. The research goal of the tool requires the recording of any relevant variable even if their usefulness is not immediately clear.
- The quality of the capture should be enough to allow advanced analysis. For example, audio recordings should be clear enough to allow speech recognition, recording of the face of the student should provide enough resolution to allow gaze and expression recognition, writing recording should be good enough to enable script and sketch recognition.

Any real device will have to compromise between all of these principles. For example, the quality of the recording will conflict with the portability of the device, the number of modes will conflict with the low-cost, and the research objectives will conflict with the privacy. The design presented in this paper is one instantiation of the different compromises between design principles and the current availability of technology.

3.2 Multimodal Streams

There are several personal devices that can be used to capture the activity of the student during the classroom. For example, digital pens to capture writing, movement tracking devices, such as Fitbit [1] and even electroencephalogram (EEG) recorders such as Emotiv [2]. These devices, however, only capture one or two modes. Several of these devices will be needed to track all relevant signals during a lecture. Figure 1 illustrates how the MRD will capture student's activity and environment within the classroom. The MRD should be placed on the student's desk, within the view of the student, and it will capture the following modes:

- **Video of the face:** The device will have a low-cost camera pointed to the student's face. The objective of capturing this mode is to establish the gaze, facial expression and head movements.
- **Close range audio:** The device will have a small microphone to capture the audio produced and heard by the student. The objective of capturing this mode

[1] Fitbit: https://www.fitbit.com
[2] Emotiv: https://www.emotiv.com

is to establish noise levels and capturing inter-student conversations and voiced opinions. The microphones can also be used to synchronize the devices through audio signals.

- **Pen strokes:** The device will integrate a digital pen to capture the pen strokes made by the student in any paper. The technology used by the digital pen should allow the capture of the strokes over any surface. The objective of capturing this mode will be to analyze the note-taking behavior and the analysis of those notes.

- **Environmental context:** The device will integrate other sensors to measure temperature, humidity and light intensity that could provide information about the environment where the lecture is taking place. These variables could be later correlated with the student's performance or attention span during class (e.g. high temperature and humidity could have a negative impact in attention span).

The MRD will connect to the classroom's WiFi infrastructure to upload and synchronize all shared data. The processing of the signals should be made in the device itself, as feasible, to avoid sharing the raw data.

3.3 Hardware Design

A first prototype for the MRD (Figure 2) to test the capabilities and usability of the device can be built with the following components:

- **Main processor:** Any micro-computer available today could serve as the main processor of the MRD. The selected component for the prototype is the Intel Edison [3]. This is a x86-compatible computer that is low-cost, has a small-form factor, low-power consumption, and has integrated WiFi and Bluetooth communications. It also provides a breakout board kit to easily connect sensors.

- **Video capture:** Video will be captured by a Micro-USB CMOS Camera. A typical CMOS camera such as the OmniVision OV7725 [4] can capture video with a 640x480 resolution at 30 fps while consuming around 100mA. It has a USB 2.0 port that will connect to the USB-OTG port on the Intel Edison Breakout Board.

- **Audio capture:** The audio will be captured by a digital MEMS microphone. These microphones are typically used in mobile phones and are cheap, small and power efficient. For example, the ICS-43432 [5] provides a good noise-bed (65db SNR), miniature size (4x3x1mm), low power consumption (1mA) and connects to the Edison's I^2S port.

- **Digital Pen:** Any digital pen based on ultrasound technology can be used to capture the pen strokes. For this prototype the Wacom Inkling [6] will be used. This pen will connect to our device via its Bluetooth interface and it does not require special paper.

- **Environmental Sensors:** Any low-cost sensor to measure temperature and humidity available for DIY projects can be connected to the Edison Board through analog inputs extensions. For the light level and the noise level, the camera and the microphone array, respectively, can be used.

- **Storage:** To store all digital streams, the device should have a non-volatile solid-state memory. In the case of the prototype, any generic Micro SD card, with at least 32Gb of capacity can be connected to the breakout board of the Intel Edison.

- **Power:** The device will be battery powered; a small Polymer Lithium Ion Battery of 2000 mAh will provide enough power for several hours (two to three sessions, depending on use). It will include a USB charger module to allow recharging with any generic mobile phone USB charger.

- **Control interface:** At minimum the prototype should provide a switch to turn on the device, a button to start or stop the recording and a multi-color LED to signal if the device is turned on and if it is recording. Future designs could include a small touch-sensing LCD screen to convert the recorder in an input device for other educational applications, such as a clicker.

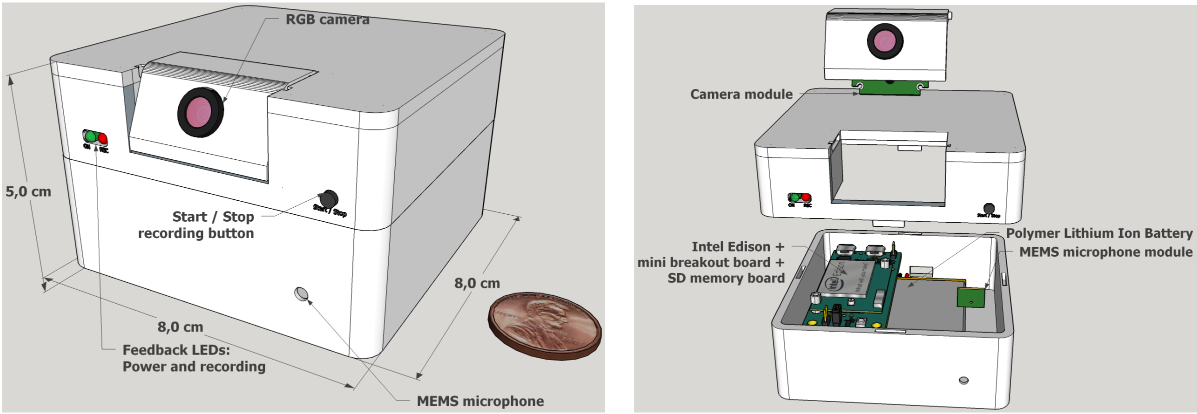
The hardware mentioned is just an example of how such a device can be built with readily available parts. A more polished design will use specialized components. For example, instead of using an available digital pen, an OEM version could be integrated in the same board as the processor. This level of optimization can only be reached with high-volume production. The prototype specified in Figure 2 presents two LEDs for feedback and one single button for turning on the device (long press) and start/stop a recording (short press).

3.4 Applications for the Proposed Design

The proposed MRD has several potential applications. These applications generate and added value to the following subjects: students, teachers, institutions and researchers.

- **Value proposition for students:** The MRD could be used as a personal device, in the same way as a tablet (video, audio, photos), but the captured content (notes) can be synchronized with the rest of the signals from the lecture. Therefore, a student could know, for instance, what happened in the lecture, when she/he wrote a special symbol or note, which in other circumstances would have no meaning, when revisited by a student. Additionally, students could also share their notes and produce content summarization or highlight sections of other students' notes, that got unnoticed when she/he first "attended" to the lecture. This MRD could be used to do crowd sourcing when learning, as in [6], since it can get access to the internet and thus other participants can support students in different and innovative ways.

[3]Intel Edison: https://www-ssl.intel.com/content/www/us/en/do-it-yourself/edison.html
[4]Camera: http://www.ovt.com/products/sensor.php?id=80
[5]Microphone: http://www.invensense.com/products/digital/ics-43432/
[6]Digital Pen: http://inkling.wacom.com/



(a) Dimensions and scale diagram

(b) Exploded view diagram

Figure 2: The MRD has a front-facing camera and microphone, a single button to start and stop recording, and two LEDs for providing feedback (green LED for power and red LED for recording activity). The device is based on the Intel Edison System on Module platform and includes a rechargeable battery with enough capacity to last for several hours.

- **Value proposition for teacher:** Teachers from all levels of expertise could benefit when using this device; for instance, they could detect when students' attention was the highest or the lowest and take further actions in their teaching plans. In parallel, the system that records the teachers' performance could get synchronized to students' signals allowing teachers to critically review their performance.
- **Value proposition for institution:** In several higher education institutions, peer-evaluation is part of the monitoring and feedback lecturers receive. Nevertheless, having another professor or colleague seated at the back of a classroom might generate tension within the class environment. The multi-sychronized signals obtained from the proposed system could be used by a third party to analyze them in a private space and to further give feedback to lecturers, which in turn would diminish anxiety from the side of novice professors.
- **Value proposition for researchers:** The large amount of data generated by the proposed system, as well as its varied diversity would be valuable resources for researchers to find patterns in behaviors observed in students and lecturers. Quality of notes, actual learning in real environments, discourses, quality of interactions between students in the classroom, quality of learning when notes are revisited, patterns of note revisions, and more, are just a few examples of the different type of topics researchers can get interested in as a consequence of using the data generated by the proposed device and its related applications.

4. ANALYSIS OF THE DESIGN

Even if not tested with students, from the description of the design of the MRD several analysis can be performed. This section will provide some discussion about the relative cost, scalability, flexibility and intrusiveness of the device. Also, it will discuss the quality of the data that can be captured.

Table 1: Bill of materials of the MRD prototype

Part	Quantity	Cost
Processor: Intel Edison + Board	1	80
Storage: Micro SD card 32 Gb	1	20
Power: LiPo 2000 mAh + Charger	1	23
Camera: OmniVision OV7725	1	35
Microphone: ICS-43432	1	12
Digital Pen: Wacom Inkling	1	80
Temp. and Humidity Sensor: RHT03	1	10
Switch	2	1
LEDs	2	1
Casing and wiring	1	10
Total	**274 USD**	

4.1 Cost

One of the design principles behind the MRD is that it should cost almost the same as a low-end smart phone (100 to 150 USD). The cost of the MRD can be estimated with a bill of materials (BOM) consisting of the discrete components described in the Hardware Design section (Table 1). The prices were obtained from consumer sites at the time of writing. As it can be seen from the table, the total cost of building the prototype is 274 USD.

While 274 is higher than the desired 100-150 range, the cost of the prototype is a ceiling of the actual cost that the device could have. Volume production and integration into a single product will bring costs down. It is expected that the final cost of such a device will be closer or inside the desired range.

The device will be owned by the student. In such an scheme, the device, even if subsidized by the educational institution, should provide a tangible value to the student in order to be attractive. The device should be marketed as a digital pen plus a lecture recorder at around 50 USD.

4.2 Scalability

One of the strong points of the design is its scalability. Due to its distributed nature, the number of students that use the device does not have a major impact in the complexity of the recording solution.

The only major scalability issue is WiFi availability as each device will be connected to the wireless network. However, if no connection is available at the moment, the transmission needed to share the recording can be made after the lecture ends.

4.3 Flexibility

The MRD provides several levels of flexibility. First, it is flexible to class configuration. As each student positions the device in front of her/him, the recording will take place regardless of the sitting scheme. It can even be adapted to other settings, such as sitting in groups or standing around a table. The only restriction for the use of the MRD is if no surface is present in front of the student (standing setup) or if there is constant movement in the classroom (walking or outdoor design).

In addition, the functionality of the MRD is flexible. While the main function of the MRD is recording video, audio, strokes and environment, it can be extended to be used as a clicker or calculator or to capture other types of modes (bio-signals or motion, for example).

Finally, the design is flexible enough to be constructed as an addition to existing devices such as cellphones or laptops. With a clever hardware design and the right software, an smart phone can be converted into a MRD.

4.4 Intrusiveness

The MRD is an intrusive device in the sense that it is not a transparent recorder of the lecture. However, given that the device provides students additional functionalities, it becomes a technological part of the classroom, such as a projector, a clicker or an electronic whiteboard. Moreover, the personal, purposeful and voluntary use of the MRD makes it as intrusive as the use of pens for note-taking.

The main sources of intrusion: setting and starting or stopping the device can be offset by a clever mechanical design and automation functions such as starting by audible tones triggered by the instructor or stopping after a period of inactivity. The device can also be controlled and configured by the student using its Bluetooth interface. Actions such as selecting which data to share, configuring WiFi or downloading notes can be implemented via this interface.

4.5 Data Quality

The main purpose of the MRD is to collect data for further learning analytics. As such, it is very important that the recorded multimodal streams have the required quality to conduct such analysis. The focus of this subsection will be the analysis of the quality of the three main signals: video, audio and pen strokes. Other captured modes are briefly discussed.

4.5.1 Video

In a common scenario, that is, the device resting on the desk, the MRD will capture video with a minimum resolution of 640x480 at the 40-60 cm range in a not-zoomed slightly low-angle shot (Figure 3). In this setup, the face dimensions take, in average, 180 pixels wide (ear-to-ear) and 200 pixels tall (hair line to chin). This resolution is enough for face recognition [34], gaze estimation [21] and basic facial expression estimation [31].

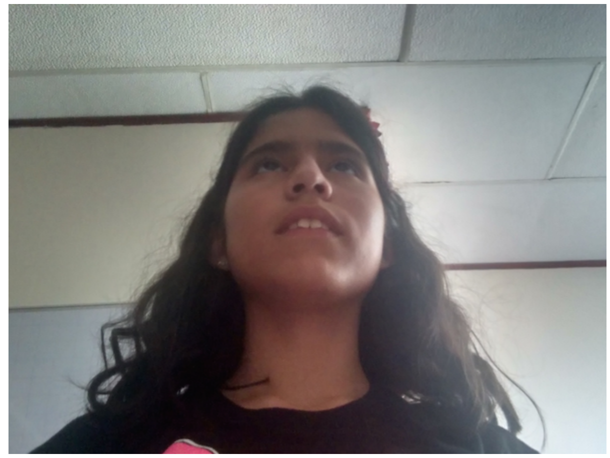


Figure 3: Example shot from 640x480 camera at 40-60 cm range

4.5.2 Audio

The microphone used in the MRD, a digital MEMS microphone, is a low cost, low-power consumption component with a dynamic range and SNR similar or better than their electret microphone counterparts [20]. The latest model can provide a 65db SNR, more than enough for prosodic analysis, speaker identification and usable speech recognition [1].

4.5.3 Pen Strokes

The current resolution of digital pens exceed the resolution for handwriting recognition and sketch recognition. Given that the MRD will use a commercial digital pen or an OEM integrated version, no temporal or spatial resolutions problems are expected.

4.5.4 Other Modes

The MRD will be able to record other signals through their respective sensor. In the prototype, humidity and temperature are sampled and recorded. The main limitations that these measurements could have are the actual analog limitations of the sensor.

In the foreseen types of analysis of contextual variables, the temporal resolution required will be in the order of seconds or minutes. Even the most basic processors can provide at least one order of magnitude faster sampling.

5. CONCLUSIONS AND FURTHER WORK

The main contribution of this design is the change of paradigm between centralized to distributed recording to establish student behavior in class. This solution has the potential to greatly reduce the privacy concerns that centralized systems raise among students and academics.

The design process of the Multimodal Recording Device showed that such a device can be built with existing technology at a relative low cost and provide the necessary quality to conduct learning analytics over the captured data. However, the introduction of such a device should be accompanied by a group of applications that provide immediate and tangible value to both students and instructors.

The next step needed to evaluate the MRD design is to test the prototype in a real lecture environment. The test will consist on taking a sizable number of multimodal recordings (at least 30) and apply state-of-the-art algorithms to automatically extract features that are likely to be part of any learning analytics application, such as attention measurement. If the error-rate of the automatic extraction of features is on par with what the state-of-the-art algorithm produces when fed with more intrusive recordings, the MRD will be proved useful to record that specific feature. Due to the variety of modes and variety of features to extract, this evaluation will require a considerable amount of work.

The most important evaluation of the MRD tool, however, does not involve the application of data-mining algorithms for automatic feature extraction. To obtain a real indication of the viability of the MRD, its usefulness for students has to be evaluated. This evaluation can only be conducted in the context of a much larger system described in the Application Design subsection. If the MRD tool can enable a collaborative note-taking system that is perceived as useful to the students, then it has the possibility of being introduced in the classroom and could produce data that can be used for learning analytics research.

Finally, this work is also meant as a discussion-starter for the design and implementation of more discrete and decentralized measurement instruments that shift the power relation that traditional data capturing schemes establish.

6. ACKNOWLEDGMENTS

The authors want to acknowledge the support of the SENESCYT Project "Andamios".

7. REFERENCES

[1] A. Acero. *Acoustical and environmental robustness in automatic speech recognition*, volume 201. Springer Science & Business Media, 2012.

[2] J. A. Brotherton and G. D. Abowd. Lessons learned from eclass: Assessing automated capture and access in the classroom. *ACM Trans. Comput.-Hum. Interact.*, 11(2):121–155, June 2004.

[3] A. Buckland and A. Quigley. Csct-computer supported cooperative teaching. In *Proceedings of The International Symposium on Pervasive Displays*, page 188. ACM, 2014.

[4] R. Buckland. Open teaching a case study on publishing lecture videos publicly. In *Proceedings of the Thirteenth Australasian Computing Education Conference - Volume 114*, ACE '11, pages 19–28, Darlinghurst, Australia, Australia, 2011. Australian Computer Society, Inc.

[5] P. Dillenbourg and M. Evans. Interactive tabletops in education. *International Journal of Computer-Supported Collaborative Learning*, 6(4):491–514, 2011.

[6] S. Dow, E. Gerber, and A. Wong. A pilot study of using crowds in the classroom. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 227–236. ACM, 2013.

[7] H. Du, M. B. Rosson, J. M. Carroll, and C. Ganoe. I felt like a contributing member of the class: increasing class participation with classcommons. In *Proceedings of the ACM 2009 international conference on Supporting group work*, pages 233–242. ACM, 2009.

[8] R. Flewitt*. Conducting research with young children: some ethical considerations. *Early Child Development and Care*, 175(6):553–565, 2005.

[9] R. Flewitt. Using video to investigate preschool classroom interaction: education research assumptions and methodological practices. *Visual Communication*, 5(1):25–50, 2006.

[10] E. González-Agulla, J. L. Alba-Castro, H. Canto, and V. Goyanes. Galitracker: Real-time lecturer-tracking for lecture capturing. In *Multimedia (ISM), 2013 IEEE International Symposium on*, pages 462–467. IEEE, 2013.

[11] R. Granda, V. Echeverría, K. Chiluiza, and M. Wong-Villacrés. Supporting the assessment of collaborative design activities in multi-tabletop classrooms. *Conference Proceedings in the Third Asia-Pacific Conference on Computer Aided System Engineering (APCASE). In Press.*, pages 270–275, Jul 2015.

[12] G. R. Hayes and G. D. Abowd. Tensions in designing capture technologies for an evidence-based care community. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '06, pages 937–946, New York, NY, USA, 2006. ACM.

[13] G. R. Hayes, J. A. Kientz, K. N. Truong, D. R. White, G. D. Abowd, and T. Pering. Designing capture applications to support the education of children with autism. In *UbiComp 2004: Ubiquitous Computing*, pages 161–178. Springer, 2004.

[14] A. Jones, A. Kendira, D. Lenne, T. Gidel, and C. Moulin. The tatin-pic project: A multi-modal collaborative work environment for preliminary design. In *Computer Supported Cooperative Work in Design (CSCWD), 2011 15th International Conference on*, pages 154–161, June 2011.

[15] M. Ketterl, O. A. Schulte, and A. Hochman. Opencast matterhorn: A community-driven open source solution for creation, management and distribution of audio and video in academia. In *2009 11th IEEE International Symposium on Multimedia*, pages 687–692. IEEE, 2009.

[16] A. Kharrufa, M. Balaam, P. Heslop, D. Leat, P. Dolan, and P. Olivier. Tables in the wild: lessons learned from a large-scale multi-tabletop deployment. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 1021–1030. ACM, 2013.

[17] J. Kim, E. L. Glassman, A. Monroy-Hernández, and M. R. Morris. Rimes: Embedding interactive multimedia exercises in lecture videos. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, CHI '15, pages 1535–1544, New York, NY, USA, 2015. ACM.

[18] S. Kokolakis. Privacy attitudes and privacy behaviour: A review of current research on the privacy paradox phenomenon. *Computers & Security*, 2015.

[19] M. Kranzberg. Technology and history:" kranzberg's laws". *Technology and culture*, pages 544–560, 1986.

[20] J. Lewis and P. Schreier. Low Self Noise: The First Step to High Performance MEMS Microphone Applications. Technical report, InvenSense, 2013.

[21] Y.-T. Lin, R.-Y. Lin, Y.-C. Lin, and G. C. Lee. Real-time eye-gaze estimation using a low-resolution webcam. *Multimedia tools and applications*, 65(3):543–568, 2013.

[22] Y. Mao, H. Li, and Z. Yin. Who missed the class?: Unifying multi-face detection, tracking and recognition in videos. In *Multimedia and Expo (ICME), 2014 IEEE International Conference on*, pages 1–6, July 2014.

[23] R. Martinez Maldonado, Y. Dimitriadis, J. Kay, K. Yacef, and M.-T. Edbauer. Orchestrating a multi-tabletop classroom: From activity design to enactment and reflection. In *Proceedings of the 2012 ACM International Conference on Interactive Tabletops and Surfaces*, ITS '12, pages 119–128, New York, NY, USA, 2012. ACM.

[24] A. Pardo and G. Siemens. Ethical and privacy principles for learning analytics. *British Journal of Educational Technology*, 45(3):438–450, 2014.

[25] M. Raca and P. Dillenbourg. System for assessing classroom attention. In *Proceedings of the Third International Conference on Learning Analytics and Knowledge*, LAK '13, pages 265–269, New York, NY, USA, 2013. ACM.

[26] M. Raca and P. Dillenbourg. Holistic analysis of the classroom. In *Proceedings of the 2014 ACM Workshop on Multimodal Learning Analytics Workshop and Grand Challenge*, MLA '14, pages 13–20, New York, NY, USA, 2014. ACM.

[27] M. Raca, R. Tormey, and P. Dillenbourg. Student motion and it" s potential as a classroom performance metric. In *3rd International Workshop on Teaching Analytics (IWTA)*, number EPFL-TALK-188524, 2013.

[28] M. Raca, R. Tormey, and P. Dillenbourg. Sleepers' lag - study on motion and attention. In *Proceedings of the Fourth International Conference on Learning Analytics And Knowledge*, LAK '14, pages 36–43, New York, NY, USA, 2014. ACM.

[29] B. Rosenstein. Video use in social science research and program evaluation. *International Journal of Qualitative Methods*, 1(3):22–43, 2008.

[30] M. Sabin and J. Leone. It education 2.0. In *Proceedings of the 10th ACM Conference on SIG-information Technology Education*, SIGITE '09, pages 91–99, New York, NY, USA, 2009. ACM.

[31] G. Sandbach, S. Zafeiriou, M. Pantic, and L. Yin. Static and dynamic 3d facial expression recognition: A comprehensive survey. *Image and Vision Computing*, 30(10):683–697, 2012.

[32] S. Slade and P. Prinsloo. Learning analytics ethical issues and dilemmas. *American Behavioral Scientist*, 57(10):1510–1529, 2013.

[33] S. Vahdati, C. Lange, and S. Auer. Opencourseware observatory: Does the quality of opencourseware live up to its promise? In *Proceedings of the Fifth International Conference on Learning Analytics And Knowledge*, LAK '15, pages 73–82, New York, NY, USA, 2015. ACM.

[34] W. W. Zou and P. C. Yuen. Very low resolution face recognition problem. *Image Processing, IEEE Transactions on*, 21(1):327–340, 2012.