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Front Pages

Athens Journal of Technology & Engineering

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The current issue is the third of the tenth volume of the *Athens Journal of Technology & Engineering (AJTE),* published by the Engineering & Architecture Division of ATINER.

Gregory T. Papanikos, President, ATINER.

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24-27 June 2024, Athens, Greece

The Civil Engineering Unit of ATINER is organizing its **14th Annual International Conference on Civil Engineering, 24-27 June 2024, Athens, Greece** sponsored by the Athens Journal of Technology & Engineering. The aim of the conference is to bring together academics and researchers of all areas of Civil Engineering other related areas. You may participate as stream leader, presenter of one paper, chair of a session or observer. Please submit a proposal using the form available (https://www.atiner.gr/2024/FORM-CIV.doc).

Academic Members Responsible for the Conference

- **Dr. Dimitrios Goulias**, Head, Civil Engineering Unit, ATINER and Associate Professor & Director of Undergraduate Studies Civil & Environmental Engineering Department, University of Maryland, USA.

Important Dates

- Abstract Submission: **21 November 2023**
- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **27 May 2024**

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- Greek Night Entertainment (This is the official dinner of the conference)
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- Mycenae Visit
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Details can be found at: https://www.atiner.gr/fees

Athens Institute for Education and Research

A World Association of Academics and Researchers

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The Industrial Engineering Unit of ATINER will hold its **12th Annual International Conference on Industrial, Systems and Design Engineering, 24-27 June 2024, Athens, Greece** sponsored by the Athens Journal of Technology & Engineering.The aim of the conference is to bring together academics, researchers and professionals in areas of Industrial, Systems, Design Engineering and related subjects. You may participate as stream leader, presenter of one paper, chair of a session or observer. Please submit a proposal using the form available (https://www.atiner.gr/2024/FORM-IND.doc).

Important Dates

- Abstract Submission: **21 November 2023**
- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **27 May 2024**

Academic Member Responsible for the Conference

- **Dr. Theodore Trafalis**, Director, Engineering & Architecture Division, ATINER, Professor of Industrial & Systems Engineering and Director, Optimization & Intelligent Systems Laboratory, The University of Oklahoma, USA.

Social and Educational Program

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Quantifying Shallow-Depth Concrete Delamination using Impact-Echo

By Mantaka Mahjabin Momo, Nur Yazdani± & Eyosias Beneberu°*

Corrosion-induced concrete deck delamination is quite common in bridges. Locating these embedded delaminations is important to assess the extent of the damage, the remaining member capacity and any necessary rehabilitation. The impact-echo (IE) is a simple and straightforward non-destructive testing (NDT) technique by which the depth and extent of concrete delamination may be estimated. It is effective in detecting the location and determining the depth of relatively deep delaminations in concrete. Delaminations that occur near the concrete surface can also be detected by the IE method. However, the exact depth cannot be quantified due to difficulties in analysing the flexural mode that dominates the vibration response over the corresponding delaminated region. This study developed an IE-based procedure to quantitatively estimate the depth of shallow depth delaminations in concrete slab members. Four slab specimens were prepared, each with three artificial delaminations with varying shapes and sizes at shallow depths. The frequency contour maps showed good agreement with the actual location of the delaminations. The perimeter-to-depth ratio of the delaminated region can be used to analyze the flexural mode vibration frequency. Two equations are proposed that relate the depth of arbitrarily shaped delaminations to the flexural mode vibration frequency measured over the shallow-depth delaminations.

Keywords: *impact echo, concrete delamination, concrete slabs, flexural mode vibration, non-destructive evaluation (NDE)*

Introduction

Near-surface delaminations, a defect that may be commonly found in concrete slabs and bridge decks, play a significant role in decreasing structural integrity. They can form due to steel reinforcing bar corrosion. If they are not detected early in their formation stage, the defects may keep growing with time, resulting in the need for interventions in the form of costly large-scale repairs and retrofitting of the affected structures.

Non-destructive testing (NDT) methods can be being used successfully to detect damage within concrete structures, and several NDT methods in particular have shown potential for locating internal delaminations. In general, each NDT method is best suited for characterizing a specific type of deterioration (Gucunski et al. 2017). For example, ground penetrating radar (GPR) can detect corrosive environment which indirectly implies the likelihood of delaminated region within

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the structure. Infrared thermography (IR) detects the subsurface defects by using temperature dependent electromagnetic radiation surface radiation (Kee et al. 2012). The Impact Echo (IE) is a mechanical wave-based NDT technique that has been widely and effectively used in identifying the location and extent of the delaminated regions (Kee et al. 2012, Gucunski et al. 2012, Zhu and Popovics 2007). In this method, a short duration impact is applied on the test surface and the subsequent vibration response is received by a transducer placed close to the point of impact. The transient stress pulse generated from the applied impact propagates through the structure as three stress waves, namely P-, S- and R-waves. The time domain signal acquired from the transducer can be converted into frequency domain by using fast Fourier transform (FFT). If the transducer is placed close to the impact point, the response is dominated by the P-wave (Carino 2001, Carino and Sansalone 1990, Cheng and Sansalone 1993a, Sansalone and Carino 1986). The peak frequency, f in the amplitude spectrum is related to the depth of reflecting interface and the P-wave velocity, C_p, in accordance with the following equation:

$$f = \frac{0.96 C_P}{2T} \tag{1}$$

where, T = the distance between the two reflecting surfaces (top surface and delamination)

Equation 1 is used to evaluate the IE test results and is based on the repetitive arrival of the P-wave as it undergoes multiple reflection between the two reflecting surfaces. This particular mode is the thickness mode frequency, but in the presence of shallow delamination, the flexural mode vibration of the delaminate portion of the plate dominates the frequency response. The depth up to which the IE flexural mode dominates the response is around 102 mm (12), and any depth smaller than this value is referred to as a shallow depth in this study. This vibration mode represents the out-of-plane movement of the section above the delaminated region and depends on several parameters, such as the material properties, boundary conditions and the geometry of the delaminated section (Kee and Gucunski 2016). Consequently, the IE-detected flexural mode of vibration cannot be interpreted by Equation 1.

In a previous study (Cheng and Sansalone 1993a), an analytical model, based on the flexural vibration of a simply supported thick plate, was proposed to estimate the vibration response of shallow depth delaminations. However, the model yielded erroneous results, because the boundaries for the delaminated section were more rigid than the assumed simply supported boundary condition. Another study found that the response above a shallow depth delamination lies between the simply supported and clamped boundary conditions of classical thin plate vibration (Oh et al. 2013b). In this study, the edge effect, with a correction function, was employed as a simple semi-analytical expression to relate the flexural mode of vibration to the geometry of delamination for a width-to-depth ratio greater than five. Another semi-analytical formulation was proposed, in which the rectangular delaminated region was converted to an equivalent square shape with a width of "*c*", and the geometry of the delamination was correlated with the flexural mode vibration frequency (Kee and Gucunski 2016). This study suggested that the effect of the type of boundary condition increases as the width-to-depth ratio (*c/h*) decreases, and it is more prominent when this ratio is less than five. These previous studies considered only regularly-shaped (rectangular, square, or circular) delaminations, and the suggested analytical expressions were based on the length or width of the simulated delaminations. In practice, delaminations have arbitrary shapes and may not have any well-defined lengths or widths. It is apparent that the previous studies were limited in scope in terms of unsuitability for quantifying arbitrarily shaped shallow-depth delaminations. This severely limits the applicability of these existing models. The current study was undertaken to fill this important knowledge gap by developing an analytical expression that can interpret the IE-detected flexural vibration mode for arbitrarily-shaped delaminations and also estimate the depth of shallow-depth delaminations.

Test Specimens

Four reinforced concrete slabs with artificially created delaminations were prepared. The slabs were 150 mm thick and had dimensions of 1200 x 1200 mm. The thickness was chosen so that the artificial delaminations could be placed at shallow depths, as it has been reported that the IE flexural vibration response is excited only if the delamination is shallower than 100 mm (Impact-Echo User's Manual 2001). Each slab contained three artificial delaminations, as shown in Figure 1. The delaminations were simulated by acrylic sheets (of 2.36 mm thick) with specific shapes and sizes that were covered with two layers of plastic sheets, as shown in Figure 3. To facilitate the positioning of the delaminations, two layers of # 4 (12.7 mm) bars were placed along orthogonal directions, and the delaminations were placed on top of the reinforcing bars at depths of either 38 mm or 83 mm depth. Plan and cross section views of Slab 2 are presented in Figure 2. The delamination designations and corresponding depths, areas and perimeters are given in Table 1.

Figure 1. *Slab Plan Views with Delaminations Shaded in Black and Grid Used for Testing*

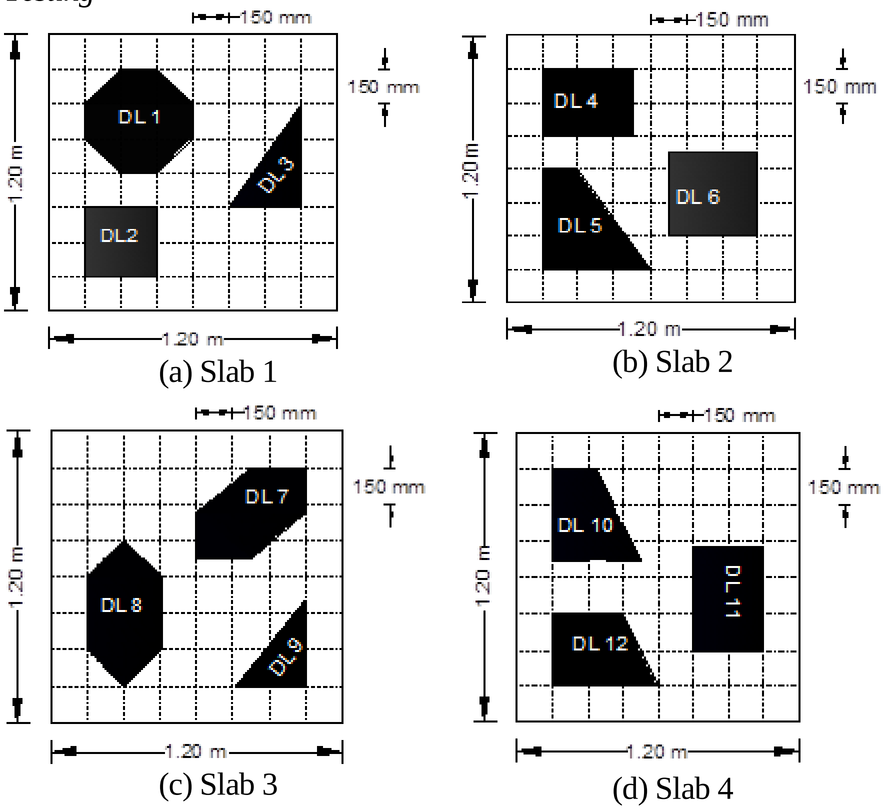


Figure 2. *Slab 2 Plan and Cross Section Views with Additional Details*

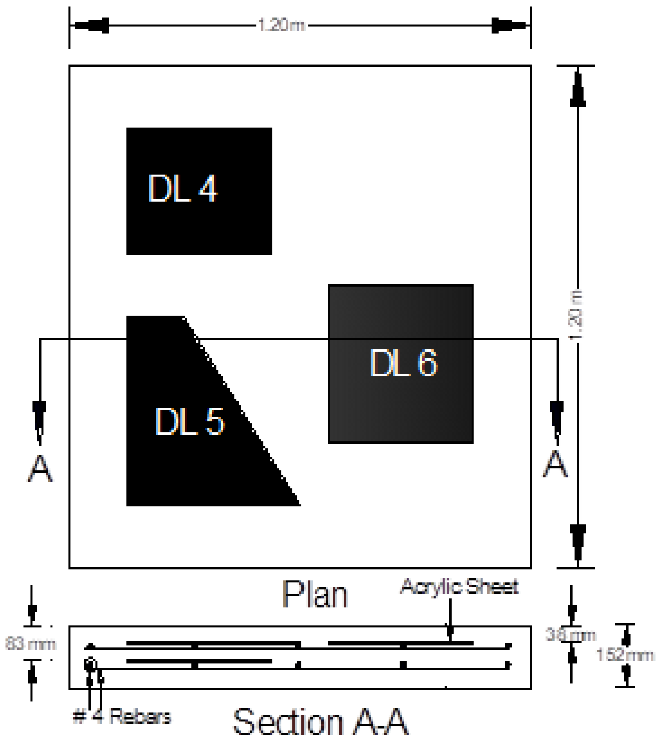
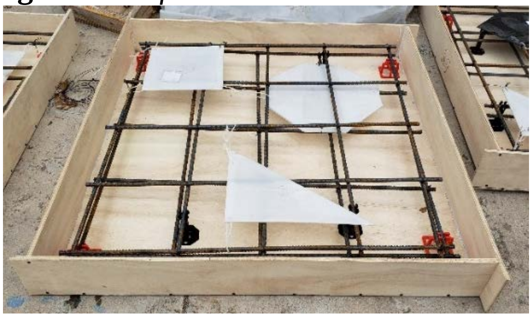
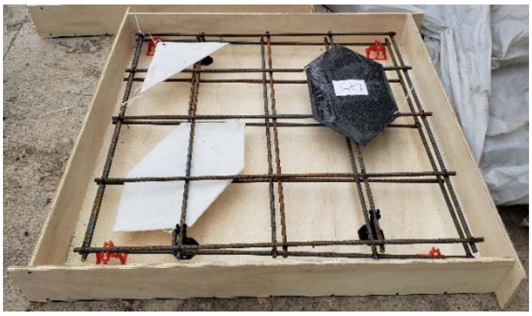


Figure 3. *Prefabricated Delamination Placement*



(a) Slab 1

(b) Slab 2



(c) Slab 3

(d) Slab 4

Table 1. *Detailed Information of the Prefabricated Delaminations*

Delamination No.	Shape	Area (m^2)	Perimeter (m)	Depth (mm)
DL1	Octagon	0.16	1.5	83
DL2	Rectangle	0.09	1.2	38
DL3	Triangle	0.07	1.3	38
DL4	Rectangle	0.12	1.4	83
DL5	Trapezoid	0.14	1.6	38
DL6	Rectangle	0.15	1.5	38
DL7	Hexagon	0.14	1.5	83
DL8	Hexagon	0.14	1.5	38
DL9	Triangle	0.06	1.1	38
DL10	Trapezoid	0.11	1.4	83
DL11	Rectangle	0.12	1.4	38
DL12	Trapezoid	0.11	1.4	38

Specimen Preparation

Typical concrete mixture proportions used for the test slabs is presented in Table 2. The target slump and com-pressive strength at 28 days were 200 mm and 20.7 MPa, respectively. The test slabs were cast from a single batch of ready-mix concrete from a local plant. Plywood formwork was used. After application of curing compound, the slabs were cured for 28 days. The concrete compressive strength was determined from the average of three cylindrical specimens (100 x 200 mm size), evaluated in accordance with ASTM C39/C39M (ASTM 2020) at 28 day age.

Table 2. *Concrete Mix Design*

Ingredient	Amount (kg/m³)
Cement	201
Fly Ash	51
Water	141
Coarse aggregate	1098
Fine aggregate (Bristol sand)	214
Fine aggregate (Bridgeport sand)	640

NDE Procedure

We used a commercially available Impact Echo (IE) device with the following characteristics. It has an LCD backlit touch screen with a touchscreen keyboard for entering 5-character file names, depicted in Figure 4. For the signal input it has up to 4 wide band channels with 16 bit analog/digital converters. The equipment includes a test head with a solenoid impactor and built-in transducer as shown in Figure 5. The impactor applies force on the test surface, the corresponding vibration response is measured by the transducer, and the transducer response is analyzed and displayed on the display platform.

Figure 4. *Components of the IE System (Test Head, Cable, and Display Unit)*

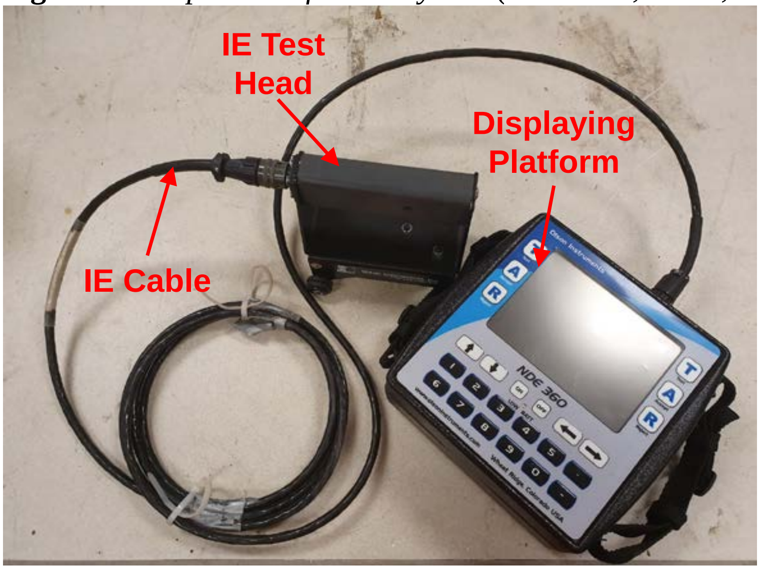
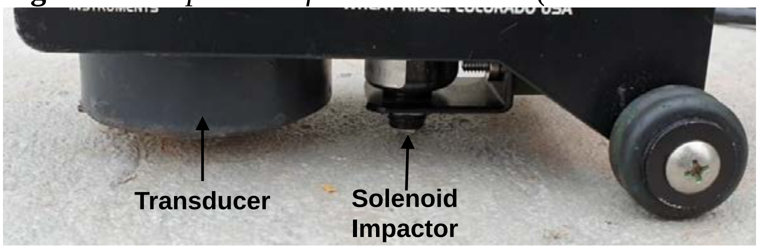


Figure 5. *Components of the IE Test Head (Transducer and Solenoid Impactor)*



For the IE testing, a 150 x 150 mm grid pattern as shown in Figure 1. This grid size was selected so that there would be multiple test point over each delamination. Previous studies used both 300 x 300 mm and 150 x 150 mm grid spacings (Lee et al. 2017, Kee and Gucunski 2016). We used the smaller grid size as our specimens were relatively small.

For testing, the test head was firmly pressed at each grid point in sequence and the solenoid impactor was activated. The collected waveforms were stored and then post-processed. The P-wave velocity obtained from tests at solid locations was 3232 m/s, constant at each grid point. The peak frequency at each grid point was determined by using the WinIE software (Olson Instruments, Inc. 2016). In accordance with Equation 1, the thickness frequency at the solid portion is 10.3 kHz. Similarly, the thickness mode frequency for delaminations at 38mm will be 40.8 kHz and for the delaminations at 83mm this value will be 18.7 kHz.

Results and Discussion

The first step in the data analysis was to determine the frequency at each grid point. Frequency contour maps with zones of high and low frequency were drawn, as shown in Figure 6, using Surfer v18 software. The shape of the artificial delaminations, shown in bold lines, are superimposed with color-coded IE flexural frequency response and corresponding contour lines. The delaminations at 83 mm depth correspond to the high frequency red zones on the contour maps, and the delaminations at 38 mm depth correspond to the low frequency blue zones. This allowed us to conveniently distinguish between the delaminations at different depths. Equation 2 was used in this study as the basis to determine the depth of the delaminations corresponding to the average frequency. The equation represents the theoretical frequency of the fundamental flexural mode of vibration of a thin rectangular plate with simply supported boundary conditions (Mitchell and Hazell 1987).

$$f = \frac{\pi}{2}\left(\frac{1}{a^2}+\frac{1}{b^2}\right)\sqrt{\frac{D}{\rho h}} = \frac{\pi}{2A^2}\left(\frac{P^2}{4}-2A\right)\sqrt{\frac{D}{\rho h}} = C_{rec}^2\frac{\pi}{2h^2}\sqrt{\frac{\cdot}{\rho}} \qquad (2)$$

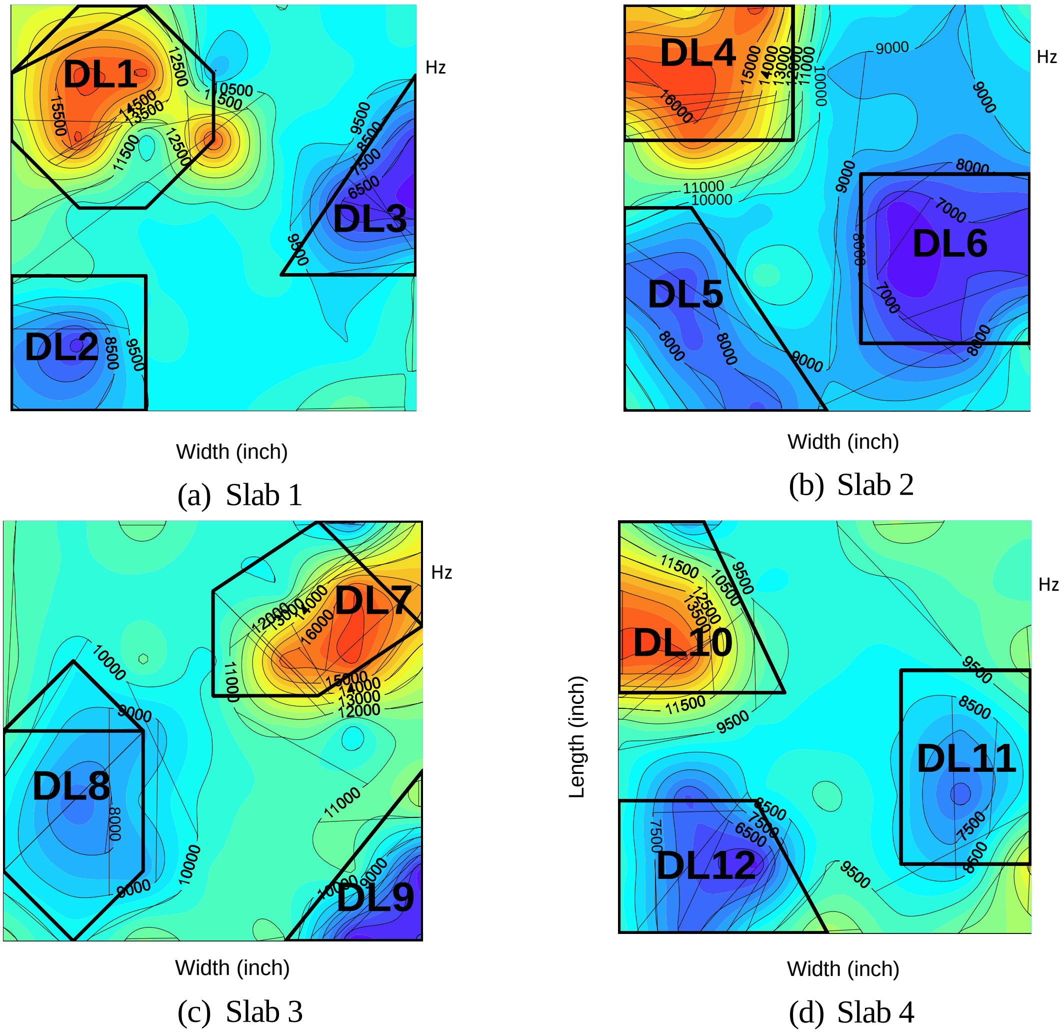
where,

f = Fundamental Frequency for flexural mode of vibration of a simply supported thin rectangle plate
E = Young's Modulus of Elasticity
ρ = Mass Density
h = Depth of Delamination (Plate Thickness)
ϑ = Poisson's Ratio
a, b = Length and Width of Plate
P = Perimeter of Rectangular Plate
A = Planar Area of Rectangular Plate

$$D = \text{Flexural Rigidity} = \frac{Eh^3}{12(1-\vartheta^2)}$$

$$C_{rec}^2 = \frac{h^2}{A^2}\left(\frac{P^2}{4} - 2A\right)$$

Figure 6. *Frequency Contour Maps (1 inch = 25 mm)*



The proposed frequency formulation for our study, based on Equation 2, is presented in Equation 3. The boundary conditions for actual concrete delaminations are in between simply supported and clamped support conditions. To represent the support conditions and the arbitrary shape of delamination, Equation 3 includes a dimensionless frequency term, C_{DL}^2.

$$f_{DL} = C_{DL}^2 \frac{\pi}{2h^2}\sqrt{\frac{D}{\rho h}} = C_{DL}^2 \frac{\pi}{h} \times \frac{C_p}{(1-\vartheta)}\sqrt{\frac{(1-2\vartheta)}{48}} \qquad (3)$$

where,

f_{DL} = Flexural Mode of Frequency for Arbitrarily Shaped Delaminated Plate

C_{DL}^2 = Dimensionless Frequency

$$P - \text{wave velocity}, C_p = \sqrt{\frac{E(1-\vartheta)}{\rho(1+\vartheta)(1-2\vartheta)}} \qquad (4)$$

Regression analysis was performed using RStudio software to express the dimensionless frequency in terms of geometric parameters of the delaminations. Three parameters were selected for this purpose (P/h, h/b, Ph/A), as shown in Equations 5, 6 and 7.

$$C_{DL}^2 = \text{func}\left(\frac{P}{h}\right) \qquad (5)$$

$$C_{DL}^2 = \text{func}\left(\frac{h}{b}\right) \qquad (6)$$

$$C_{DL}^2 = \text{func}\left(\frac{Ph}{A}\right) \qquad (7)$$

where,

P = Perimeter of Delaminated Region

A = Area of Delaminated Region

h = Depth of Delamination

$$\frac{1}{b^2} = \frac{1}{A^2}\left(\frac{P^2}{4} - 2A\right)$$

Graphs were drawn of the dimensionless frequency as a function of the selected parameters. Linear, logarithmic, and exponential functions were fitted. The relationships expressed in Equations 5, 6 and 7 could best be represented by logarithmic and exponential functions. Accordingly, six regression equations were established, as shown in Table 3. All best fit equations yielded *F*-values greater than 1.0 and *P*-values less than 0.05 indicating that these functions are statistically significant. After the regression analysis was completed, the best fit functions for C_{DL}^2 were substituted into Equation 3, and the delamination depths were estimated based on the frequencies measured over the delaminations.

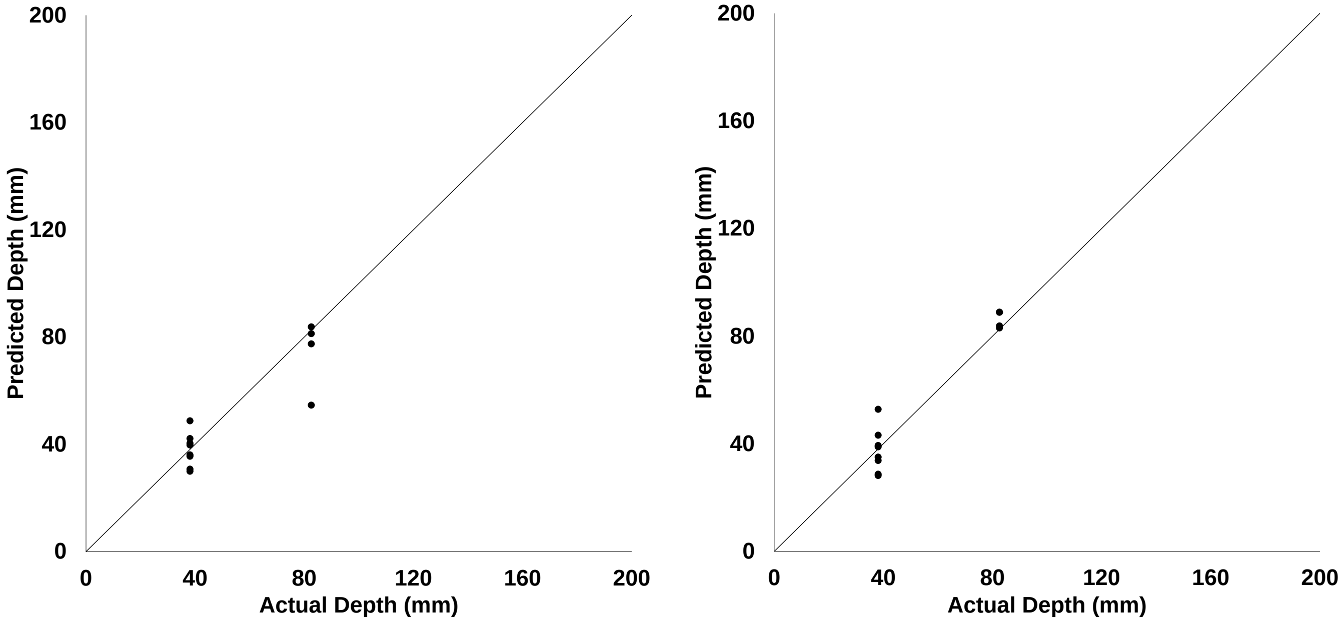
The regression functions were established for known delamination geometries and depths, while the depth estimations extend the models to unknown geometries and depths. Table 3 shows that Equation A and B were the most statistically significant with Equation A the best of all with an R^2 value of 0.932. Therefore, these two models, which are based on the delamination parameter P/h were selected for additional assessment. Graphical representations of the actual and estimated concrete delamination depths for these two models are shown in Figure

7. The actual depth is the planned value used in making the specimens. Numerical comparison of the actual and estimated depths, along with the error percentages, are shown in Table 6.

Table 3. *Regression Analysis Results*

Equation No.	Equation from Regression Analysis	Form	R^2	*F*-value	*P*-value
A	$C_{DL}^2 = 3.068 - 0.785 \times \ln\left(\frac{P}{h}\right)$	Logarithmic	0.932	151.7	$2.287\text{x}10^{-7}$
B	$C_{DL}^2 = 2.22e^{-0.060272\left(\frac{P}{h}\right)}$	Exponential	0.883	84.28	$3.46\text{x}10^{-6}$
C	$C_{DL}^2 = 1.308 + 0.574 \times \ln\left(\frac{h}{b}\right)$	Logarithmic	0.434	9.434	0.01181
D	$C_{DL}^2 = 0.106e^{5.19718\left(\frac{h}{b}\right)}$	Exponential	0.465	10.58	0.008677
E	$C_{DL}^2 = 0.783 + 0.691 \times \ln\left(\frac{Ph}{A}\right)$	Logarithmic	0.623	19.21	0.001371
F	$C_{DL}^2 = 0.0816e^{2.293294\left(\frac{Ph}{A}\right)}$	Exponential	0.6847	24.88	0.0005467

Figure 7. *Actual vs. Estimated Delamination Depths*



(a) Equation A (Logarithmic) (b) Equation B (Exponential)

Table 4. Estimated vs. Actual Depths Based on Eq. A and B

Delamination	Actual Depth (mm)	$f_{DL} = \text{func}\left(\frac{P}{h}\right) \times \frac{\pi}{h} \times \frac{C_p}{(1-\vartheta)}\sqrt{\frac{(1-2\vartheta)}{48}}$			
		Equation A		Equation B	
		Estimated Depth (mm)	Error (%)	Estimated Depth (mm)	Error (%)
DL1	83	81	-1.54	89	7.69
DL2	38	31	-19.27	28	-26.00
DL3	38	36	-6.67	35	-8.00
DL4	83	77	-6.15	84	1.54
DL5	38	49	28.00	53	33.3
DL6	38	40	6.00	39	2.00
DL7	83	84	1.54	89	7.69
DL8	38	42	10.67	43	13.33
DL9	38	30	-21.33	29	-24.67
DL10	83	55	-33.85	83	0.62
DL11	38	40	4.33	39	3.33
DL12	38	36	-5.33	34	-11.33
Average Errors (%)			12		11.6

The actual and estimated values are equal on the solid lines shown in Figure 7. The average errors shown in Table 4 for Equation B and Equation A are practically identical. The percentage of error in the estimated is less than 13%, except for delaminations DL2, DL5, and DL9. Therefore, it may be concluded that both the logarithmic (Equation A) and the exponential (Equation B) correlations of the dimensionless frequency term with perimeter-to-depth ratio are effective in estimating the depth of shallow delaminations of arbitrary shape. The finalized models relating the IE frequency and delamination depth are presented in Equation 7 and 8. Users can consider either of these two models as desired:

$$\text{Measured } f_{DL} = \left(3.0681853 - 0.7851072 \times \ln\left(\frac{P}{h}\right)\right) \times \frac{\pi}{h} \times \frac{C_p}{(1-\vartheta)}\sqrt{\frac{(1-2\vartheta)}{48}} \quad (7)$$

$$\text{Measured } f_{DL} = 2.22e^{-0.060272\left(\frac{P}{h}\right)} \times \frac{\pi}{h} \times \frac{C_p}{(1-\vartheta)}\sqrt{\frac{(1-2\vartheta)}{48}} \quad (8)$$

Additional IE data points were collected around the edge of the delaminations for these three delaminations, as shown in Table 5. As a correct IE signal may not be interpreted around the edge due to wave scattering attenuation (Kee and Gucunski 2016), a high percentage of error was observed.

Table 5. Location of Points where IE Data was Collected

Delamination	Edge	Internal	Corner
DL1	8	4	8
DL2	8	1	4
DL3	5	1	2
DL4	7	2	2
DL5	7	3	3
DL6	5	4	2
DL7	4	4	1
DL8	8	3	6
DL9	5	1	2
DL10	4	3	1
DL11	4	2	1
DL12	5	2	1

Limitations of the Study

This study has the following limitations:

1. Only two depth levels of delaminations were considered. It is recommended that artificial delaminations be placed at more than two depth levels to further verify the findings of this research.
2. Concrete delaminations in the field will typically have irregular and arbitrary shapes without geometrically sharp corners. Although irregular shaped delaminations were used in this research, they still had sharp corners at the edges which may not fully represent the response of actual delaminations in the field.
3. The proposed models for estimating the depth of arbitrarily shaped delaminations require knowing the perimeter of delamination.

Conclusions and Recommendations

The conclusions drawn from this study, as well as recommendations for future research, are as follows:

- An equation was proposed to estimate the depth of shallow delaminations that is based on the vibration theory of thin rectangular plates with simply supported boundary conditions.
- A dimensionless frequency term was introduced to consider the arbitrary geometry and the semi-clamped boundary conditions of real delamination.
- Tests were conducted on four slabs containing artificial delaminations. The impact-echo test was performed at grid points on the slabs, and the average frequency was determined for each delamination. Regression analysis was

performed to correlate the calculated non dimensional frequency term to the geometry of the delaminations. Six regression functions were proposed, and the functions with the greatest statistical significance were used to relate the frequency of shallow depth delaminations to the depth and P wave speed.

- Both regular-and-irregular-shaped prefabricated delaminations were used in this study which is a unique feature of this research. From the observations it was concluded that the flexural mode frequency measured over a shallow-depth delamination is related to the perimeter-to-depth ratio of the delamination.
- Three parameters, the flexural mode frequency, the P wave velocity, and the perimeter of the delamination, must be known to determine the depth of the shallow depth delamination from Equation 7, or 8. The frequency and the P-wave velocity can be directly obtained from the IE test. In this study, the known perimeter of the artificial delamination was used to estimate the depth. Further research is required to determine the perimeter of the delamination by using the frequency contour map derived from the IE test.
- Due to rough edges and corner points, erroneous results may occur, as they did for DL2, DL5, and DL9. It has been recommended that circular-shaped delaminations, as well as delaminations with curved edges, be used to avoid such errors.
- This study was conducted with 12 delaminations placed in four slab specimens at two depth levels. The number of slab specimens could be increased and the delaminations could be placed at more than two depth levels to obtain a more refined result from the statistical analysis.
- Research to determine whether the response obtained from part of the delamination can be used to predict the depth could be beneficial for interpreting the field data.

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Transforming CS Curricula into EU-Standardized Micro-Credentials

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Micro-credentials are a way to integrate flexible learning pathways into the classic forms of education defined in the European Qualification Framework (EQF). They allow members of the workforce to get necessary skills described, certified, and recognized in a transparent and portable way. One way for universities to enter this market for lifelong learning is to convert existing study programs into smaller units, namely, micro-credentials. This process of converting a study program consisting of modules into small, independent pieces is called unbundling. When unbundling a program, the existing modules have to be converted to a standard EU-wide recognizable form. In this paper, we will describe the process we used to convert modules from our study program at DHBW. The first step converts the skill descriptions into a standard form. Since there is no common accepted formal standard, we use the Dublin descriptors as a way to structure the skills on the different abstraction levels, and ESCO-terms as a widely used standardized vocabulary. The second step breaks down modules of 3-12 ECTS into smaller constituents (each ECTS corresponds to a workload of around 30 hours). Typical micro-credentials have a size of 1 to 3 ECTS, a group or stack of micro-credentials corresponds to one module.

Keywords: *micro-credentials, curriculum design, internationalization, computer science, learning outcomes, standardization*

Introduction

The European skills agenda from 2020 names micro-credentials (MC) as an important tool for citizens to develop future skills demanded by employers. They serve the purpose of supporting life-long learning and international validity of certificates for distributed learning in time and space. To document this personal record, platforms like Europass[1] are developed and rolled out. To enable the recognition of courses including their assessments, it is essential to define outcomes, competences and skills in a standardized manner that everyone can interpret at an international level. In the EU, qualification frameworks define levels of achievement in the different Bologna cycles. Dublin Descriptors[2] define one such framework by describing levels of learning through "generic statements of typical expectations of achievements and abilities associated with qualifications

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[1]https://europa.eu/europass/en.
[2]https://www.aqu.cat/doc/doc_24496811_1.pdf.

that represent the end of each of a Bologna cycle". These levels can be used to structure the learning outcomes within module descriptions from basic facts, their application, or critical reflection and communication on the given topics. A significant component of the standardization of learning outcomes is a controlled vocabulary that defines the different skills. The ESCO classification provides such terms for some areas (ESCO)[3].

In addition to providing personalized learning paths, such a standardized structure forms the basis of learning data that can support comparative studies as well as best practices. Open educational resources can be indexed uniformly as a function of best practices. Any such comparative study is very difficult without these standards. In particular, these MCs pave the way for learning path definitions that will be multidisciplinary in future. One such example is "Data Science" that combines domain knowledge, technology, and mathematics. Such a degree is highly personalized and enabled through MCs. Using EU-standards for MCs supports unification of module descriptions on several levels: (1) Learning outcomes formulation (skills) sorted by level (Dublin Descriptors) (2) Teaching content formulation (knowledge) (3) groupings into smaller, modular, and stackable components, and finally (4) assessment and activities. Especially, transversal and interdisciplinary skills can be described for MCs with ESCO. A more detailed discussion of this aspect can be found in section 4.

Currently, most universities do not follow common standards when describing competences and skills in module descriptions. "Traditionally higher education was relatively explicit about the knowledge (outcomes) to be achieved, or at least the knowledge covered by the curriculum. It was however somewhat less explicit on the skills or competences required for the award of a given qualification. Competences, such as those of critical evaluation, were and are embedded or implicit in the assessment values and practices." (Bologna Working Group 2005, p. 63) The same goes for ethics, security, or sustainability. Principally, module descriptions are difficult to standardize across modules and even more so across majors as their authors differ and are often untrained in this matter. The current process, therefore, frequently leads to inconsistencies.

This problem is even more complicated than usual with DHBW (our university) because of size and history, from our website: "Baden-Wuerttemberg Cooperative State University (Duale Hochschule Baden-Württemberg/DHBW) is the first higher education institution in Germany which combines on-the-job training and academic studies and, therefore, achieves a close integration of theory and practice, both being components of cooperative education. With around 34,000 enrolled students, over 9,000 partner companies and more than 145,000 graduates, DHBW counts as one of the largest higher education institutions in the German Federal State of Baden-Wuerttemberg."[4] Being large and distributed over 10 campuses, running study programs in parallel, makes coordination difficult and slow. As a result, a change to our (many) module descriptions to adapt EU standards requires a prolonged change-process.

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[3]https://esco.ec.europa.eu/en/classification/skill_main.
[4]https://www.dhbw.de/english/dhbw/about-us.

In this paper, the authors present representative examples of learning outcomes from very simple to highly complex. We will show the process of converting from the existing more or less "free form" definition into a standardized form using Dublin Descriptors and ESCO-terms. The process is designed to be generalizable into a methodology for others in order to follow guiding steps during conversion of new modules. We will point out lessons learned and pitfalls to avoid along the way, and elaborate on the following steps:

1. Analysing learning outcomes in modules
2. Assigning Dublin Descriptors to learning outcomes
3. Associating standard formulations
4. Creating stackable sub-modules (micro-credentials)
5. Editing the online micro-credentials

Micro-credentials

Although there is no global consensus about the term MC the indication is always the same: MCs are usually short, flexible, and modular learning programs that can be stacked and completed in much less time than the traditional degree programs. In the last years there was a significant push towards the interest for these small units but as the relevance of MC increased, the lack of definitions and processes towards creating MC has become evident (Brown et al. 2021).

The European Union started an approach to support lifelong learning and employability through short, flexible, and modular learning programs with their Council Recommendation in 2022[5]. This recommendation aims to establish a common understanding and recognition of MCs across the EU to reach their full potential. According to this resolution, the EU describes a MC as follows:

> "'Micro-credential' means the record of the learning outcomes that a learner has acquired following a small volume of learning. These learning outcomes will have been assessed against transparent and clearly defined criteria. Learning experiences leading to micro-credentials are designed to provide the learner with specific knowledge, skills and competences that respond to societal, personal, cultural or labour market needs. Micro-credentials are owned by the learner, can be shared and are portable. They may be stand-alone or combined into larger credentials. They are underpinned by quality assurance following agreed standards in the relevant sector or area of activity." (Council of the European Union 2022, p. 5)

This definition already gives an idea of the enormous advantages offered by MCs. They are an attractive option for professional development as they allow individuals to acquire new skills quickly and individually. On the one hand, they help individuals to stay competitive in the job market by demonstrating their expertise in a particular area and on the other hand, employers can identify and recruit individuals with specific skills as well as provide a way to train and upskill

[5]https://eur-lex.europa.eu/legal-ontent/EN/TXT/?uri=uriserv:OJ.C_.2022.243.01.0010.01.ENG

current employees. So overall, MCs are a valuable tool for both individuals and organizations providing a flexible and accessible way to acquire and validate specific skills or competences (European Commission 2020).

According to the definition of the EU, there are still two main issues that need to be solved: First, the "transparent and clearly defined criteria" for the learning outcomes to achieve a well-defined set of knowledge, skills and competences have to be defined. Additionally, there must be a recognized standard that validates this set to ensure the quality of those small units (Council of the European Union 2022).

Since MCs are gaining popularity and the use continues to grow, it is important to quickly establish common standards and recognized frameworks that ensure the value and credibility of MCs in the education and employment sectors (UNESCO 2022).

Dublin Descriptors

The European MOOC Consortium (massive open online courses) collaborates on a Common Microcredential Framework (CMF) which aims to combine the learning outcomes in higher education and professional training. Those programs consist of 4 to 6 ECTS and can be certificated to fit into Europass. To assure the quality of the programs the ENQA Guidelines are used as a reference framework. The CMF uses the qualification levels taken from EFQ to be fully compatible with the qualifications under the Bologna Process (European MOOC Consortium 2019).

While the EQF defines skill levels that allow comparison between qualification systems, its definition of skill levels is too abstract to be used to classify learning outcomes (European Commission 2008). This level of detail is possible using Dublin Descriptors, that are compatible with the EQF:

> "In the QF-EHEA [Dublin Descriptors being adopted in EHEA], learning outcomes are understood as descriptions of what a learner is expected to know, to understand and to do at the end of the respective cycle" (ibid, p. 10). That is precisely what is needed in a module description or a definition of the outcomes of a MC. "The Dublin descriptors refer to the following five dimensions: 'knowledge and understanding', 'applying knowledge and understanding', 'making judgements', 'communication' and 'learning skills'. Whereas the first three dimensions are mainly covered by the knowledge and skills dimensions in the EQF, the EQF does not explicitly refer to key competences such as communication, or meta-competences, such as learning to learn" (ibid). Those are the transversal skills also needed in defining learning outcomes of a module or a MC. The ESCO[6] terms provide a standard vocabulary for these skills.

[6]https://esco.ec.europa.eu/.

Table 1. *Overview of the Five Levels of the Dublin Descriptors Including Their Description (Taken from Joint Quality Initiative Informal Group 2004) Supplemented by Exemplary Keywords and Sentences*

Level	Title	Description: The students …
Keywords		***Example***
1	knowledge & understanding	have demonstrated knowledge and understanding in a field of study that builds upon and their general secondary education, and is typically at a level that, whilst supported by advanced textbooks, includes some aspects that will be informed by knowledge of the forefront of their field of study;
know, understand, describe, comprehend, …		*The students know the software devlopment process with scrum.*
2	applying knowledge & understanding	can apply their knowledge and understanding in a manner that indicates a professional approach to their work or vocation, and have competences typically demonstrated through devising and sustaining arguments and solving problems within their field of
apply, implement, develop, utilize, execute, …		*The students can use the scrum process for their project management.*
3	making judgements	have the ability to gather and interpret relevant data (usually within their field of study) to inform judgements that include reflection on relevant social, scientific or ethical issues;
analyse, choose, argue, reason about, improve, …		*The students can improve the scrum process so that it fits best to their project.*
4	communication	can communicate information, ideas, problems and solutions to both specialist and non-specialist audiences;
communicate, discuss, exchange ideas, cooperate, present, mediate, debate, …		*The students can discuss the scrum process and exchange ideas for improvement.*
5	learning skills	have developed those learning skills that are necessary for them to continue to undertake further study with a high degree of autonomy.
acquire knowledge, deepen knowledge, transfer finding, generalise, teach, …		*The students can transfer their knowledge about scrum to other software development processes.*

Table 1 provides an overview of the five dimensions of the Dublin Descriptors and associated examples for possible formulations. Of course, Dublin Descriptors are only one way to define skill levels. The well-known Blooms Taxonomy could also be used. So, Dublin Descriptors and Blooms Taxonomy are pretty much exchangeable and serve the purpose of sorting things nicely. It has no relationship with standardizing the formulation through ESCO, which is the more important standard that serves to unify the description on an EU (or international) basis. But since the Dublin Descriptors are accepted by the EU (see above) and provide an easily understandable layering with each level built on top of the next lower one, we use that.

Converting the Module Description

Step 1: Analysing Learning Outcomes in Modules

The first step in the conversion analyzes the curriculum description, especially the learning outcomes, to apply the Dublin Descriptor framework. In our case this includes translating the text to (at least) the English language. The next step is to reduce complex sentences and enumerations into simple, single topic sentences like “Students can apply X”, “They can implement Y” or “They can develop Z”. Sometimes it was necessary to combine sentences, but only in very few cases. Learning outcomes on a higher abstraction level have to be phrased accordingly like “Students can … (analyze, choose, argue, reason about, improve, …)” (see Table 1). This process repeats for all skills of the module description and will lead to a list of statements sorted by Dublin Descriptor levels.

Example Transformation of Learning Outcomes

In the following sections we will show only selected examples from a first cycle module in Software Engineering. The complete module description, before and after conversion, can be found on github[7].

Let’s start with the German original “Die Studierenden kennen die Grundlagen des Softwareerstellungsprozesses”. In Step 1 we translate that to English and split it up (not necessary for this example) in simple sentences. We get “The students know the basics of the software development process.”

Step 2: Assigning Dublin Descriptors to Learning Outcomes

In step 2 we associate a Dublin Descriptor level: When analyzing the verbs we find “The students know …” This corresponds to level 1. In the next step, we try to find a corresponding ESCO skill or a corresponding ISCED category. In this case we get an appropriate ESCO skill (knowledge): “ICT project management methodologies”.

The next example is a bit more complex:

> “Sie können eine vorgegebene Problemstellung analysieren und rechnergestützt Lösungen entwerfen, umsetzen, qualitätssichern und dokumentieren.”

Translated to English we get: “They are able to analyze a given problem and can use computer based tools to design, develop, assure quality and document solutions.” Split this up in simple parts gives (step 1): “They can analyze a given problem. They can use computer based tools for communication and problem

[7]https://github.com/TillHaenisch2/MicroCred.

solving. They can design and develop a solution for a given problem. They can assure the quality of the solution. They can document solutions." Based on the vocabulary used, we order these learning outcomes by Dublin Descriptor levels (step 2):

> DD2: "They can design and develop a solution for a given problem.", "They can document solutions.", "They can use computer based tools for communication and problem solving."
> DD3: "They can analyze a given problem."

Step 3: Associating Standard Formulations

Now we have to associate standard terms for the skills and competences. We won't do that for all the skills given in the example but only for some edge cases, see Table 2.

Table 2. *Corresponding ESCO-Terms for Given Skills and Competences*

"They can analyze a given problem"	S2.7.4 analyze business requirements
"They can design and develop a solution for a given problem"	S1.11.1 designing ICT systems or applications
"They can use computer based tools for communication and problem solving"	S5.6 using digital tools for collaboration, content creation and problem solving.

But that doesn't work always: "Sie können korrigierende Anpassungen an Lösungsvorschlägen vornehmen". In English: "They can correct design decisions" doesn't exist in ESCO yet. In this case we need to propose a new term S4.9+ "correcting design decisions" as the ESCO criteria are incomplete and don't offer a corresponding term.

> Or: "Sie können für konkrete Problemstellungen angemessene Methoden auswählen."
> In English: "The students can choose appropriate methods to solve a given problem."

That would correspond to level 2 or 3 in the Dublin Descriptors.

In ESCO there are either broader or narrower terms, so we need a new skill "Software development lifecycle models" as a generic term for the subcategories under "ICT project management methodologies".

To modify or add ESCO categories one has to differentiate between two types of changes: There are small and large changes.

An amendment to the given text is a small change, that can be done quickly. Adding a new skill is a major change that has a larger delay in implementation as it goes through a central consortium and needs to be translated to several languages.

Figure 1 shows the mapping of the German free text version to groups of skills structured according to the Dublin Descriptors, but still in the original competency framework. It would be nice to change that to a standard form too, but this is something which should be addressed in the long run since it requires changing the competence framework used for accreditation and probably will take years to be accepted.

Trying to convert the topics covered in a course and defined in the module description is a bit different than skills. These document the knowledge gained during the course.

Classifying knowledge on a high level is easier. The relevant knowledge of the example module (software engineering) is:

- Project Management Methods
- Phases of Software Engineering Process
- Requirements-Engineering and Management
- Analyses and Modelling (for example UML)
- Software architecture, APIs, Class-Diagram, DB Design
- Code quality, Reviews, Testing
- Continuous Integration
- Versioning
- Lifecycle Management
- Documentation
- Implementation of a full project

On a high level, these topics are classified by the ISCED-F (International Standard Classification of Education) classification (ISCED[8]), but the level of detail given there might not be sufficient. The relevant category for our example is ISCED-F/613 “Software and applications development and analysis” with the following subcategories (ISCED-F 613).[9]

Computer programming, Computer science, Computer systems analysis, Computer systems design, Informatics (computer science), Operating systems, Programming (computer), Programming languages development, Software development, Software localisation, Software programming, Software testing

This might not be as fine grained as needed for a module description. So, the broad topic of a course can be defined in standardized way using ISCED but probably has to be complemented with (non-standard) terms to make clear, what the course content really is. Depending on the topic, existing ESCO-terms can be used, in other areas they have to be defined. Whether this is acceptable for the recognition of MCs remains to be seen.

The output of this rather mechanical process is given in Figure 1 in the form of our standard module descriptions.

[8]https://ec.europa.eu/eurostat/statistics-explained/index.php?title=International_Standard_Classification_of_Education_(ISCED).

[9]http://data.europa.eu/esco/isced-f/06 (example for Computing).

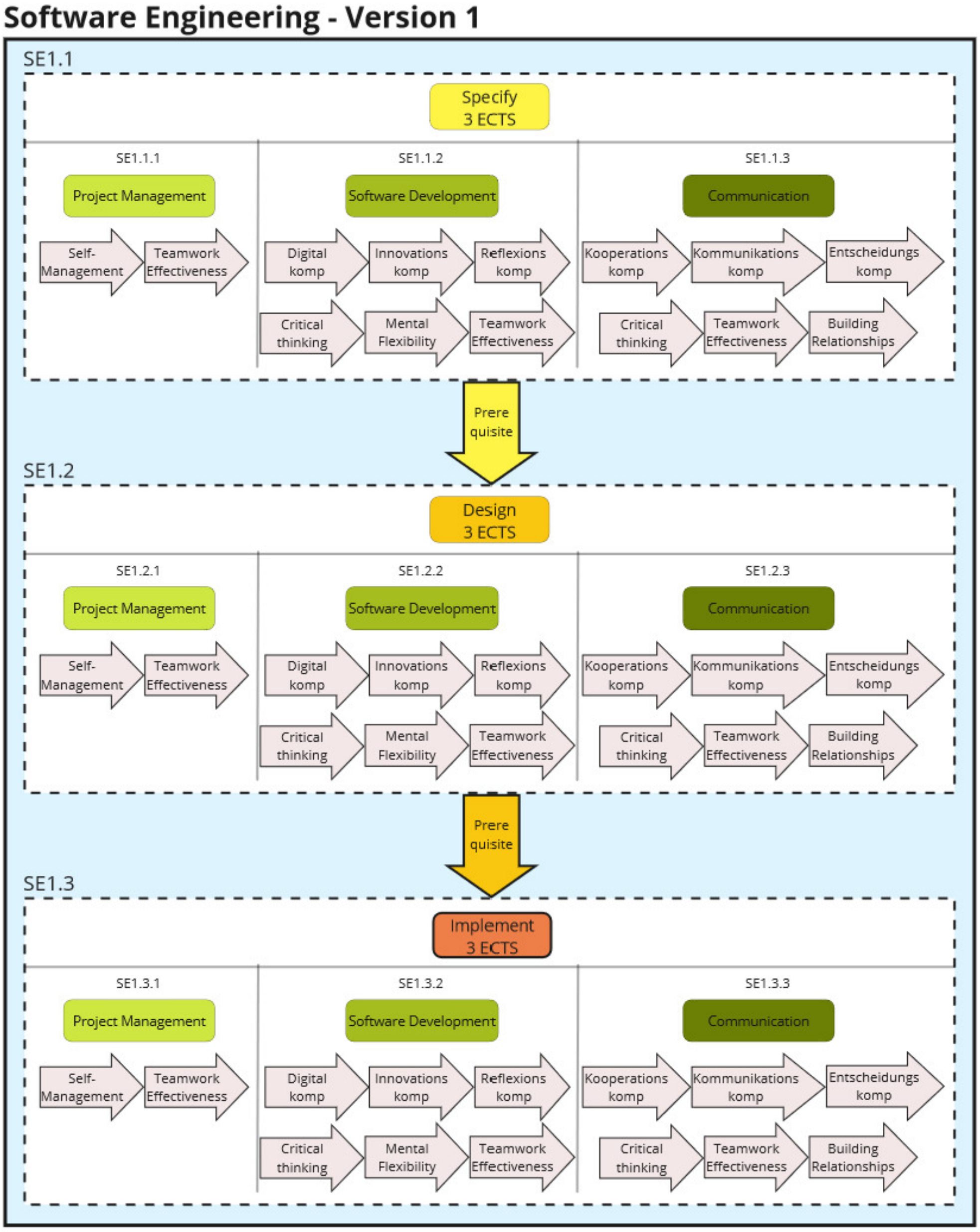
Figure 1. *Skills and Knowledges Converted to Standard Terms*

QUALIFIKATIONSZIELE UND KOMPETENZEN
FACHKOMPETENZ (DD1)
know technical designs, procedures, methods, tools or activities
METHODENKOMPETENZ (DD2 + DD3)
analyse business requirements organising, planning and scheduling work and activities designing ICT systems or applications correcting design decisions using digital tools for collaboration, content creation and problem solving
PERSONALE UND SOZIALE KOMPETENZ (DD3 + DD4)
analysing and evaluating ICT systems and solutions negotiating presenting information working with others building and developing teams
ÜBERGREIFENDE HANDLUNGSKOMPETENZ (DD5)
thinking skills and competences planning and organising thinking creatively and innovatively working efficiently taking a proactive approach accept criticism and guidance communicating supporting others collaborating in teams and networks

Step 4: Creating Stackable Sub-Modules (Micro-Credentials)

As it can be seen in Figure 2 modules might often have a huge size, so it is necessary to break up modules into smaller "micro" units.

Figure 2. *Example Module Separated into Three Stackable Micro-Credentials*



Since MCs are defined as small units, a typical size for existing MCs is 1 to 3 ECTS, so about 3 ECTS looks like an acceptable maximum size. In our programs most modules have a size of 5 ECTS. Our example (Software Engineering I) has a size of 9 ECTS which is too big for a MC. In this case it makes sense to divide the 9 ECTS into 3 parts: design, specification, and implementation. Each of them can stand alone and be taken since each unit has individual skills and competences defined. Of course, these three MCs can be stacked if desired.

That makes sense for a first cycle computer science degree (which the module is intended and accredited for), but in other cases not. For someone working in business or health care, it might make perfect sense to acquire the skills necessary for analyzing and specifying the (business) requirements of a system while the skills to design or implement it are not needed, so they only need the first part.

When splitting a module into several parts, a few interesting questions will arise, especially with transversal skills. While assigning the skill to one (and only one) of the three parts of our sample module is easy for some skills - typically more technical skills - it might become difficult for others. We must consider three edge cases:

1. skills, which are used equally in all parts. Example: “using digital tools for collaboration, content creation and problem solving”
2. skills, which are used to some extent in more than one part but with a clear focus in one part. Example: “Requirements management” focused in part two
3. skills, which are only acquired in one part. Example: “S2.7.4 analyze business requirements” only in part one or “Code quality, review, testing” only in part three.

Case number 3 is obviously the easiest: the skill (knowledge in the example above) can be assigned to one of the parts. Case number 1 is easy from the viewpoint of assigning the skill: it must be assigned to all parts. But that is not without semantic problems:

Consider the case of two students, one takes and completes only part one, the other one all three parts. Do both have the same set of skills afterwards? Probably student number two spent more time learning “using digital tools for collaboration, content creation and problem solving”. But how do we know that, looking only at the certificate? Especially in the case, that she didn’t take three MCs but completes the module as originally intended and got only one certificate. Should the skills be weighted with the size of the course? Probably not, since several skills could be acquired in a course, not all equally important/deep. So, we cannot distinguish the two.

There is (as far as known to the authors) no standard way of handling this. Maybe we could assign points or badges or some other quantitative attribute to the skill for each MC. But that would be hard to get consistent across platforms/ universities. Maybe that only makes sense in one ecosystem to express things like: “To get the skill ‘using digital tools for collaboration, content creation and problem solving’ you need to take all three parts together or maybe take only one of these but then you need other MCs which give the missing amount of that skill.”

In the future, student administration systems in universities must be capable of handling not only lecture-names, grades and granting university. A student must have a set of MCs shown but in addition the skills must be extracted into a skill-profile. Out of such a profile, we can then determine, if a student is able to register for a new MC, without taking a specific pre-requisite. Instead, a pre-requisite is expressed by pre-required skillset. Today, moodle and most student management systems in universities are not enabled for this requirement of new learning.

Step 5: Editing the Online Micro-Credentials

The format of MC certificates is defined by the EU[10] as an XML-format. There are (web-) tools to create certificates manually, but in the long run, any XML editor can take given module descriptions and highlight problems with the texts and allow editors to change texts into sentences, looking for autocomplete that matches the current ESCO criteria and ISCED classification of knowledge. In our (DHBW) current project portfolio we have MicroCredX and EU4Dual, that work on such interfaces for MC design and future work will publish on how these ideas are implemented and integrated with our student management systems at DHBW. We plan to leverage open-source projects here and cooperate with other universities that have similar requirements.

Teachers will have to adapt their way of grading by adopting more detailed skill descriptions and using a more granular grading system. Additionally, transversal skills must be made visible within the grading scheme. The online editor or digital credential issuer uses the MC format to provide an XCEL to enter grades for each of the students based on their ID, which consists of the EU-ID or an email. After uploading the grades, all students receive a notification and can share their credentials publicly.

Conclusion and Further Research

The more or less unstructured format of our module descriptions is not adequate to capture the complexity of mapping different competence frameworks (especially in more than one language). While the visual representation we used for our work[11] has proven to be a valuable tool for structuring sample module descriptions during the process, a much more powerful way of representing the content (the learning outcomes, skills and knowledge, achievements and all the other metadata) is needed. Graph databases can be used to represent complex structures and dependencies and have been applied to capture dependencies between modules in university contexts, see for example (Samaranayake 2022). So, it should be evaluated, if a graph database is the right way to solve these problems.

MCs require reforms by universities with respect to their basic student management systems. These need to be extended to view students as life-long learners instead of full-time clients for a couple of years. A new student should be able to enter a university with all past certifications immediately accessible to the student management system. Based on this model, that includes a skill-profile, specific coursework should automatically be accredited by the current institution, outlining the remaining curricular options that are open to the student given their profile. Additionally, for dual education, skills gained during any practical phase should be taken into account. Finally, a match between employers and employees

[10] https://europa.eu/europass/digital-credentials/issuer/#/home.
[11] https://github.com/TillHaenisch2/MicroCred.

can now be based on skill-profile matching, revolutionizing future job market in a world that seeks their employees in a worldwide international market.

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Mathematical Model of HoloLens 2 Goggles Kinematics for AR Support of Flight Simulator

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The paper describes how the kinematics model of HoloLens 2 goggles mounted on the user's head is used for converting the reference frame fixed to the flight simulator with the reference frame fixed to the goggles. The constant correspondence between the two has to be kept to properly map the internal 3D space relative to the position of the device with the real 3D space of the flight simulator cockpit in which HoloLens 2 produces holographic objects. Such conversions are prerequisites of SLAM (Simultaneous Localization and Mapping) algorithms which are used by AR devices to build a map of an environment, and, at the same time, this map is used to compute the goggle's own position and orientation. In the paper, we also present the application of HoloLens 2 goggles in the WrightBroS project to support flight simulator users (pilots and/or technicians) in their training and maintenance procedures.

Keywords: *augmented reality (AR), slam, kinematics, hololens 2, flight simulators*

Introduction

The advances in flight simulators technology focus on the use of architectures supported by Augmented Reality (AR) as opposed to currently available architectures which are based solely on Virtual Reality (VR). This approach has a potential to significantly broaden the market of professional products by introducing "learn as you go" paradigm to train pilots and technical staff in operation, maintenance and servicing of these innovative products. The complete platform referred to as "LEARN AS YOU GO" is composed of the following applications:

- General image recognition engine – a special programming tool for AR.
- Cockpit procedures app – AR manual for pilots – application recognizes the cockpit of the aircraft and guides the pilot through the cockpit procedures in the pre-flight preparation mode, during all emergency procedures etc.
- Virtual maintenance and service app – application guiding technicians of the aircraft or flight simulator through the database of components, repairing procedures and logistic operations.

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This concept, when deployed in construction of flight simulators requires manufacturing of knowledge-based smart diagnostic products capable for detection of malfunctioning elements and presenting to the user step-by-step interactive instructions for making system functional. In addition, a constant alignment between two 3D spaces (internal space of AR goggles and external space of the flight simulator) needs to be kept for proper displaying of holographic images. In the paper, we focus on this latter approach by using cockpit flight simulator as an example of an electro-mechanical product characterized by complex human-machine interfaces in which a pilot is supported in his/her activities by presenting him/her holographic images created by HoloLens 2 googles. One of the prerequisites of how to achieve this alignment is described by mathematical model of HoloLens kinematics transformation. The aim of this paper is to apply the well-known mathematical formalism in the context of Augmented Reality device (HoloLens 2 goggles) working in the flight simulator cockpit (Boeing 737).

Following this introductory section, the rest of the paper contains the Literature review section (in which state-of-the-art of advances in flight simulators, augmented reality, and SLAM algorithms is presented) and Methodology section where the kinematics model of the goggles is given. Then, Results and Discussion section presents how results of the modelling are used in the AR actual system and discusses what additional components are essential for the final solution. The Conclusions, Acknowledgements and References are closing the article.

Literature Review

The enhancement of air traffic is a priority in aviation development. As new technologies are implemented, the demands on the crew's theoretical and practical skills, especially those of the pilots, are increasing. Because of their ability to mimic the virtual reality of flights, flight simulators have proven to be a powerful part of pilot training. Virtual reality, thanks to modern technology, faithfully recreates real flights, removing concerns and uncertainties among pilots, airlines, aircraft manufacturers, and regulatory agencies about its usage in training (F012-02 2009). Adopting flight simulators into pilot training lowered hazards and improved training quality, while also improving overall flying safety and lowering training and aircraft operating costs. According to research, aircraft incidents are mostly due to human errors, the pilot's inabilities, or a pilot is caught off guard by adversity and responds in an effective manner (Safety Regulation Group 2002). However, the results differ depending on the scenarios. These errors lead to a series of events that causes flight incidents.

Flight simulation uses a technique called flight simulator, to simulate the flight of an airplane and the surroundings in which it flies. In addition, it mimics the model that controls how an aircraft flies and how it responds to flight control applications and its external elements like air density, turbulence, precipitation, wind shear, cloud, etc. In this regard, augmented reality (AR) is a potential technology for developing enhanced interfaces with interactive and wearable visualization systems to apply new techniques for displaying documents as digital data and graphical databases (de Crescenzio et al. 2011).

The progress in real pilot training comes down to realism, and a large part of that is the motion tracking technology utilized in both live and simulated aircraft applications. Motion tracking is the act of establishing the spatial and temporal relationships between moving objects and the robot or between moving and stationary objects (Wang et al. 2007). To add to the visuals to move somewhat, (as they would when a pilot moves their head or changes their viewpoint in a genuine cockpit), you want to know the position furthermore, the direction of their head in 3D space. To accomplish this, a helmet or even a pair of glasses can be used to track the pilot's head throughout their range of motion in the cockpit.

Currently, several motion capture systems are found on simultaneous localization and mapping (Sturm et al. 2012). Positional tracking in virtual reality (VR) determines the exact location of head-mounted displays, controllers, other objects, and body parts in Euclidean space. Because the goal of virtual reality is to simulate real-world experiences, it's essential that positional tracking is exact and precise so that the illusion of three-dimensional space is maintained (Lang 2013).

Since its inception in the 1980s, Simultaneous Localization and Mapping (SLAM) has become a significant field that reaches across many disciplines, particularly in the fields of intelligent systems and robotics. Many people feel that solving the SLAM problem will open a world of possibilities for autonomous robots (Cadena et al. 2016). The development in tackling SLAM challenges has been swift and exciting, with several interesting implementations of SLAM approaches. To solve mapping and localization difficulties, some academics had been investigating the use of estimation-theoretic methods (Durrant-Whyte and Bailey 2006). A SLAM system must be able to estimate the robot's pose (position and orientation) in the world while also creating a map of the environment using data collected by a collection of sensors attached to the robot (Azuma et al. 2001). To navigate through a previously unknown world or to modify a map of a previously known environment, the SLAM method employs a sophisticated array of computations, algorithms, and sensory inputs (Maxwell 2013).

The foundation for scene understanding is initiating the spatial and temporal links between a robot, fixed items, and moving objects in a scene. Because of ambiguity and unobservable states in the real world, localization, mapping, and moving object tracking are challenging. Motion sensors like odometry and inertial measurement units, as well as perception sensors like cameras, radar, and laser range finders, are noisy. Without the use of additional sensors positioned on the moving items, the goals, or controlling inputs, of the mobile robots, remain unobservable (Smith et al. 1990). Due to the obvious usual mistake in predicted vehicle location, while a mobile robot drives across an unfamiliar area taking relative observations of landmarks, the estimations of these landmarks must relate to each other (Bailey and Durrant-Whyte 2006).

To build stable values through repeated exploration of the world, SLAM must ideally converge over time, which is a highly stochastic process because all calculations and outputs are expressed as probabilities. The robot keeps track of its estimated (probabilistic) position while navigating independently across an unknown environment by comparing it to a global static frame, typically situated at the starting location or a previous pose frame. It evaluates the environment around it using its sensory processes and builds a probabilistic model of the constituent parts in relation to a fixed global frame of reference.

Critically, at the map's convergence qualities or steady-state behavior. As such, it was commonly anticipated at the time that the predicted map errors would not converge and instead would follow a random walk with limitless error accumulation. Given the computational complexity of the mapping problem and the lack of knowledge about the map's convergence behavior, researchers instead focused on a series of approximations to the consistent mapping problem solution, which assumed or even forced the correlations between landmarks to be drastically reduced or eradicated, effectively reducing the full filter to a series of disconnected landmark to vehicle filters (Leonard and Durrant-Whyte 1992).

SLAM scales quadratically with the number of landmarks on a map in its most basic version. This scale could be a significant constraint in the usage of SLAM approaches in real-time applications. There have been various techniques explored to lessen this uncertainty. These techniques comprise linear-time state augmentation, information form sparsification, partitioned updates, and sub-mapping procedures.

The accurate association of landmark observations with landmarks recorded on the map is another important hurdle to overcome in the application of SLAM technologies. An inaccurate association can cause the SLAM algorithm to fail catastrophically. When a robot returns to an earlier mapped territory after a long journey, data association is very crucial; this is known as the "loop closure" issue. Batch validation approaches that utilize limitations inherent in the SLAM formulation, appearance-based methods, and multi-hypothesis procedures are some of the current data association methods employed in SLAM (Bailey and Durrant-Whyte 2006).

The major benefit of SLAM is that it does not require any artificial infrastructure or prior topological knowledge of the surroundings. A solution to the SLAM problem would be invaluable in a variety of applications where the absolute position or precise map information is unavailable, such as autonomous planetary exploration, subsea autonomous vehicles, autonomous airborne vehicles, and autonomous all-terrain vehicles in mining and construction, to name a few (Dissanayake et al. 2001).

Augmented Reality (AR) systems based on Simultaneous Localization and Mapping (SLAM) have been gaining popularity due to their promise to give users an immersive and participatory experience. By showing 3D virtual items registered in a user's natural environment, it enables users to interact with both real and computer-generated objects (Bajura and Neumann 1995). Based on the development of Simultaneous localization and mapping (SLAM) technology, users can walk about in actual space and engage with virtual objects because of this (Chi et al. 2020). Since a home user may not carefully move the AR device and the real environment may be complicated, a range of tough conditions (e.g., fast motion, powerful rotation, substantial motion blur, dynamic interference) may be easily encountered for AR applications in practice (Jinyu et al. 2019). AR approaches seek to provide users with information that is spatially consistent with the seen scene. They show this information by enhancing a camera-captured view with graphical objects that are suitably aligned with real-world 3D structures. Real-time estimation of the camera's 3D position and orientation (often referred to as the pose) in relation to the real-world objects to be enhanced is a crucial AR technology deriving from computer vision. For AR applications, the camera posture must be estimated in real-time, precisely, and without drift, and the surroundings must be represented using a metric scale. To initialize or maintain the metric scale while solving odometry progressively, current AR systems must use additional range sensors, which is their principal bottleneck. However, a potential solution lies within the SLAM algorithm which relies on visual tracking (Laviola et al. 2017).

Methodology

The kinematic model of HoloLens 2 goggles is derived from kinematics of a rigid body described for example by Bestaoui Sebbane (2012) and it is used here in the context of Augmented Reality where a match between virtual 3D space of the goggles needs to be constantly aligned to the real 3D space of external world (in our case flight simulator cockpit). The model of dynamics is omitted as the inertia of the goggles is negligible for movements of the head of the user. Thus, all functional dimensions and degrees of freedom of the goggles are mathematically described here only as kinematics. This method also includes a description of the object's workspace, positional capabilities, and limits. Depending on the axis around which the rotations are performed, there are different Euler angle conventions. The rotation in this convention is determined by the Euler angles ($\emptyset, \theta, \psi$) where:

- ψ: Yaw (around vertical axis z, head left and right movement)
- θ: Pitch (around horizontal axis y, head up and down movement)
- ϕ: Roll (around horizontal axis x, head left and right movement)

By using these angles, we denote the goggles-fixed reference frame orientation as a vector:

$$\eta_2 = \begin{bmatrix} \phi \\ \theta \\ \psi \end{bmatrix} \quad (1)$$

Further, we introduce a 3×3 rotation matrix $R(\eta_2)$, in which each column is a unit vector provided in terms of the navigation axes. Such rotation matrix is referred to as the direction cosine matrix and is used to transformation of the goggles-fixed reference frame coordinates relative to the external reference frame coordinates. From mathematics of rotations it follows that:

$R(\eta_2) = R_z(\psi)R_y(\theta)R_x(\phi)$, where:

$$R_x(\phi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\phi & sin\phi \\ 0 & -sin\phi & cos\phi \end{bmatrix}, R_y(\theta) = \begin{bmatrix} cos\theta & 0 & -sin\theta \\ 0 & 0 & 0 \\ sin\theta & 0 & cos\theta \end{bmatrix},$$

$$R_z(\psi) = \begin{bmatrix} cos\psi & sin\psi & 0 \\ -sin\psi & cos\psi & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

(2)

Hence, after computation we get:

$$R(\eta_2) = \begin{bmatrix} cos\psi\, cos\theta & -sin\psi\, cos\phi + cos\psi\, sin\theta\, sin\phi & sin\psi\, sin\phi + cos\psi\, sin\theta\, cos \\ sin\psi\, cos\theta & cos\psi\, cos\phi + sin\psi\, sin\theta\, sin\phi & -cos\psi\, sin\phi + sin\psi\, sin\theta\, cos \\ -sin\theta & cos\theta\, sin\phi & cos\theta\, cos\phi \end{bmatrix}$$

(3)

By using cosine direction matrix, we are able to convert coordinates of any point in the goggles-fixed reference frame to the corresponding coordinates in the flight simulator-fixed reference frame.

For this, we denote: $\eta_1 = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$ as a vector of coordinates of some point in the simulator-fixed frame, and $\eta'_1 = \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}$ as a vector of corresponding coordinates in the goggles-fixed frame. Then, $\eta_1 = R(\eta_2)\eta'_1$. Similarly, the linear velocities of the selected point in goggles-fixed frame, given by: $v_1 = V = \begin{bmatrix} \frac{d}{dt}x' \\ \frac{d}{dt}y' \\ \frac{d}{dt}z' \end{bmatrix}$, are transforming to linear velocities in simulator-fixed frame according to:

$$\frac{d\eta_1}{dt} = R(\eta_2)V \tag{4}$$

Note, that a set of rotation matrices $R(\eta_2)$ forms a special orthogonal group SO(3) defined as

$$SO(3) = \{R \in \Re^{3\times3}, R^T R = 1_{3\times3,}\, det(R) = 1\}. \tag{5}$$

The rotation matrix and the displacement vector are both combined into one matrix called the homogeneous transformation matrix (this representation is referred to as homogeneous matrix formulation).

Let $R(\eta_2) = [R_1(\eta_2)\ R_2(\eta_2)\ R_3(\eta_2)]$, where $R_i \in \Re^3$ (6)

Then, the homogeneous matrix formulation allows for unique representation of the orientation and position of HoloLens 2 goggles by using A_M matrix:

$$A_M = \begin{bmatrix} R(\eta_2) & \eta_1 \\ 0_{3\times 1} & 1 \end{bmatrix} = \begin{bmatrix} R_1(\eta_2) & R_2(\eta_2) & R_3(\eta_2) & \eta_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (7)$$

Set of matrices A_M is a special Euclidean group SE (3).

$$\mathrm{SE}(3) = \left\{ A_M \in \Re^{4\times 4} \middle| A_M = \begin{bmatrix} R(\eta_2) & \eta_1 \\ 0_{3\times 1} & 1 \end{bmatrix}, R(\eta_2) \in SO(3), \eta_1 \in \Re^3 \right\} \quad (8)$$

It describes transformations in three dimensions with six degrees of freedom (6DoF). Six degrees of freedom transformations, including three position vector coordinates (identifying, for example, the location of the center of mass) and three angles (e.g., Euler angles or yaw, pitch, and roll) are used to uniquely parameterize a 3×3 rotation matrix—to define the pose of a three-dimensional rigid body such as HoloLens 2 goggles in our case.

Note, that the special Euclidean group, also known as the special Euclidean transformations group, forms a Lie group as follows. Let us define S(t) as:

$$S(t) = A_m^{-1}(t)\frac{dA_M(t)}{dt} = \begin{bmatrix} R_1^T & -R_1^T\eta_1 \\ R_2^T & -R_2^T\eta_1 \\ R_3^T & -R_3^T\eta_1 \\ 0_{3\times 3} & 1 \end{bmatrix} \begin{bmatrix} \frac{dR_1}{dt} & \frac{dR_2}{dt} & \frac{dR_3}{dt} & \frac{d\eta_1}{dt} \\ 0 & 0 & 0 & 0 \end{bmatrix} =$$

$$= \begin{bmatrix} R_1^T & -R_1^T\eta_1 \\ R_2^T & -R_2^T\eta_1 \\ R_3^T & -R_3^T\eta_1 \\ 0_{3\times 3} & 1 \end{bmatrix} \begin{bmatrix} \frac{dR}{dt} & \frac{d\eta_1}{dt} \\ 0 & 0 \end{bmatrix} = \begin{bmatrix} R^T\frac{dR}{dt} & R^T\frac{d\eta_1}{dt} \\ 0_{3\times 1} & 0 \end{bmatrix} \quad (9)$$

Let $v_2 = \Omega = \begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix}$ are angular velocities in a goggles-fixed reference frame,

Then:

$$\begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix} =$$

$$\begin{bmatrix} \frac{d\phi}{dt} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\phi & sin\phi \\ 0 & -sin\phi & cos\phi \end{bmatrix} \begin{bmatrix} 0 \\ \frac{d\theta}{dt} \\ 0 \end{bmatrix} +$$

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\phi & sin\phi \\ 0 & -sin\phi & cos\phi \end{bmatrix} \begin{bmatrix} cos\theta & 0 & -sin\theta \\ 0 & 1 & 0 \\ sin\theta & 0 & cos\theta \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \frac{d\psi}{dt} \end{bmatrix} \quad (10)$$

Hence,

$$\begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & -sin\theta \\ 0 & cos\phi & sin\phi\, cos\theta \\ 0 & -sin\phi & cos\phi\, cos\theta \end{bmatrix} \begin{bmatrix} \frac{d}{dt}\phi \\ \frac{d}{dt}\theta \\ \frac{d}{dt}\psi \end{bmatrix}$$ or equivalently:

$$\begin{bmatrix} \frac{d}{dt}\phi \\ \frac{d}{dt}\theta \\ \frac{d}{dt}\psi \end{bmatrix} = \begin{bmatrix} 1 & 0 & -sin\theta \\ 0 & cos\phi & sin\phi\, cos\theta \\ 0 & -sin\phi & cos\phi\, cos\theta \end{bmatrix}^{-1} \begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix} \quad (11)$$

Now, let consider a vector that is tangential in the specific location to a curve drawn by some point, say center of a mass, of the goggles in a *SE*(3) configuration space. This vector is a tangent vector of a curve.

Note also that: $R^T \frac{dR}{dt} = \begin{bmatrix} 0 & -w_z & w_y \\ w_z & 0 & w_x \\ -w_y & w_x & 0 \end{bmatrix} = SK\left(\begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix}\right) = SK(v_2),$ (12)

Hence, given a curve $C(t)$: $[-T,T] \to SE(3)$, a set $S(t) = \frac{dC(t)}{dt}$ (of tangent vectors at arbitrary configuration of a HoloLens 2 given by $A_M(t)$) is a lie algebra se(3) with elements $S(t) \in se(3)$ given by:

$$S(t) = \frac{dC(t)}{dt} = A_M^{-1}(t)\frac{dA_M(t)}{dt} =$$

$$\begin{bmatrix} R^T \frac{dR}{dt} & R^T \frac{dn_1}{dt} \\ 0_{3\times1} & 0 \end{bmatrix} = \begin{bmatrix} 0 & -w_z & w_y & R_1^T \frac{dn_1}{dt} \\ w_z & 0 & -w_x & R_2^T \frac{dn_1}{dt} \\ -w_y & w_x & 0 & R_3^T \frac{dn_1}{dt} \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (13)$$

Now, let us define matrix J(η_2) as:

$$J(\eta_2) = \begin{bmatrix} 1 & 0 & -sin\theta \\ 0 & cos\phi & sin\phi\, cos\theta \\ 0 & -sin\phi & cos\phi\, cos\theta \end{bmatrix}^{-1} = \begin{bmatrix} 1 & sin\phi\, tan\theta & cos\phi\, tan\theta \\ 0 & cos\phi & -sin\phi \\ 0 & \frac{sin\phi}{cos\theta} & \frac{cos\phi}{cos\theta} \end{bmatrix}, \text{ then}$$

$$\frac{d\eta_2}{dt} = \begin{bmatrix} \frac{d}{dt}\phi \\ \frac{d}{dt}\theta \\ \frac{d}{dt}\psi \end{bmatrix} = J(\eta_2)\begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix} = J(\eta_2)\Omega \text{ and}$$

$$\frac{d\eta_1}{dt} = \begin{bmatrix} \frac{d}{dt}x \\ \frac{d}{dt}y \\ \frac{d}{dt}z \end{bmatrix} = R(\eta_2)\begin{bmatrix} \frac{d}{dt}x' \\ \frac{d}{dt}y' \\ \frac{d}{dt}z' \end{bmatrix} = R(\eta_2)V \quad (14)$$

Thus, we have the following 6D representation of the kinematic relationship of HoloLens 2:

$$\begin{bmatrix} \frac{d\eta_1}{dt} \\ \frac{d\eta_2}{dt} \end{bmatrix} = \begin{bmatrix} R(\eta_2) & 0_{3\times3} \\ 0_{3\times3} & J(\eta_2) \end{bmatrix}\begin{bmatrix} V \\ \Omega \end{bmatrix} = RV \quad (15)$$

Quaternions offer an intriguing alternative to Euler angles for describing the rotation of bodies in a space and have several advantages over them, including the absence of discontinuities and gimbal lock as well as mathematical simplicity. Therefore, quaternions are an excellent tool for describing how rigid bodies change when numerous rotations and translations are considered in increasingly complicated systems (Abaunza et al. 2018).

The Euler parameters of a rotation about the axis n = $\begin{bmatrix} n_x \\ n_y \\ n_z \end{bmatrix}$

by angle μ have representation of a unit quaternion q such that:

$$q = \begin{pmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{pmatrix} = \begin{pmatrix} \cos\frac{\mu}{2} \\ \sin\frac{\mu}{2} n_x \\ \sin\frac{\mu}{2} n_y \\ \sin\frac{\mu}{2} n_z \end{pmatrix}, 0\text{ K} \le \mu \le 2\pi \quad (16)$$

Thus, configuration space $SO(3)\times R^3$ is replaced here by $S^3 \times R^3$, where:

S^3 is a unit hypersphere in $R^4 : S^3 = \{x \in R^4 \text{ such that } \|x\|_2 = 1\}$

Results and Discussion

The results of aforementioned transformations between goggles (virtual 3D space) and flight simulator (real 3D space) reference frames and the application in actual AR system are based on the research program of the WrightBroS project that is aimed to develop a prototype of a new technology professional flight simulator to demonstrate the deployment of augmented reality (AR) in such environment (see Figure 1).

Figure 1. *AR Support of Flight Simulator*

Source: WrightBroS Project.

For functioning of the whole system, not only the presented above transformations between internal HoloLens 2 reference frame and the flight simulator-fixed reference frames need to be implemented (for matching these two spaces), but also the scenario player of the information provided with the goggles should be integrated. Bach et al. (2021) have described the architecture of such scenario player as a hierarchy of finite state machines. Integration of the scenario player with HoloLens 2 is still under development.

Conclusions

In the paper, the kinematic model of HoloLens 2 goggles movements (corresponding to the user head movements) has been considered. It is a theoretical basis for matching the internal (virtual) 3D space of the goggles, which move with the movement of the user's head, with the external (stationary) 3D space of the flight simulator. Application of this model to an AR system based on HoloLens 2 goggles on a head of a person working in a flight simulator environment can help in better mapping of the real space of the flight simulator with its representation in the AR system.

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Time Effective Logistics of Hybrid Image Processing Course and Laboratory

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In "pre-COVID 19" time, Braude Academic College of Engineering students enrolled in the course "Image Processing", visited frontal lectures, and, additionally, participated in the laboratories provided in the class equipped with computers. During the laboratories, students (organized in small groups – preferably by pairs) were asked to implement several image-processing algorithms explained during frontal lectures. In the frames of this course, C, C++, and C# languages are used to write code. Specifically, to write the code, students used computers with Windows 10 and Visual Studio installed. Additionally, students were asked to prepare a PowerPoint presentation, in which they were asked to analyze the results obtained. During the in-campus laboratory, students were free to ask for help, and, in case of need, the educator provided relevant explanations. When the report was ready, students demonstrated the presentation and the working code to the educator. The grading policy was that if the presentation was good enough, and if students reasonably answered the questions, they got a high grade. As a backup, students E-Mailed a presentation and the code by using a special format developed specifically for that course. Because of COVID-19 limitations, during three semesters logistics of the lectures and laboratories were changed, and, as lectures, as laboratories were provided online by using cloud services like ZOOM and Gmail. It so happens, that semester 2021-10 – 2022-03 was started as an online semester, but after three weeks, it became a hydride semester: lectures and laboratories were provided in-campus, but students had the right to stay at home and continue to use cloud services including ZOOM and Email. This change created a number of logistics problems, and, thus, some modifications were provided in an attempt to ensure fair and non-biased grading as for the students who were physically present during the lectures and laboratories, as for the students who participated remotely. In the frames of this course, each group of students prepared a set of assignment reports and two micro-project presentations. Additionally, students physically present in the class, participated in the short nonobligatory micro-exams. This paper discusses logistics decisions and their effect on the quality of the students' micro exams, assignments reports, and presentations.

Keywords: *hybrid laboratory, STEM, image processing*

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Introduction

Digital cameras, image processing algorithms, and hardware and software image processing techniques are widely used in many fields of science and technology. Today digital cameras are everywhere. Digital cameras are physically integrated into many gadgets, from smartphones to digital watches. Hence, a number of software applications for storing, processing, and analyzing images are available. In order to get "the best image", modern smartphones have a number of digital cameras, each of them having different characteristics, so that even in the simplest cases, images pass some preliminary image processing procedures. Image processing algorithms can be implemented as a software, as a firmware. Hence, it can be concluded, that applications dealing with images are to be created by programmers. But, anybody skilled in the art knows, that in order to develop memory effective and fast image processing utilities, a deep understanding of how exactly a digital camera creates an image is required. Well-known example of why a deep understanding of camera operation on the electronic level is a must is a situation when Fast Fourier Transform approach must be used. Every electronic engineer knows that CCD cameras are linear – that is: digital response is proportional to the light intensity, and that CMOS cameras are not linear in that sense; however, most software developers that did not learn basic electronics are unaware of this fact. From this, one can understand why in the field of image processing un-proportional number of software (and hardware) developers are, actually, electronic engineers. Hence, the image processing course is an essential part of the education of modern electronic engineers. Most universities provide this course after students pass advanced mathematical and introductory signal processing courses.

An essential part of most image processing courses is a computer laboratory. During the laboratory, students practically implement and explore algorithms and techniques that they studied during frontal lectures. In the "early computer days" (30–40 years before), specialized and expensive computers were needed to process images. For example, the memory of a typical PC then was less than 640 kB – so that processing of even one true color VGA image was a challenge. Those days providing an image processing laboratory was possible only in specially equipped computer class. Then, in the Braude Academic College of Engineering dedicated class equipped with expensive Silicon Graphics computers was used to provide the image processing laboratory. The digital camera then was a costly device, so that only two stations were equipped with a digital camera. The educator then monitors students' activity during the laboratory and helps in solving software and hardware problems. Obviously, there were a lot of interactions between the educator and students, so, at those times, laboratory logistics and grading process were plain and simple.

In 2005, expensive Silicon Graphics computers were replaced by a less expensive PC with Windows operational system. Still, digital cameras and compilers needed to create working code were expensive; hence specialized computer class was still needed.

Our days, the situation is completely different: nearly every student can afford a laptop with Windows OS installed, Microsoft Visual Studio is free for noncommercial usage, digital cameras are an inherent part of the laptop, and, in case of need, an inexpensive USB camera can be used to get images to be processed by the software developed by students. It is the technology progress, that enable dramatically reorganize the structure of the image processing course for the electronic engineers: specialized laboratory is not a must for the modern image processing course. Practically, starting from 2005, most students prefer to use their laptops instead of computers installed in the image processing laboratory. Then, small, but important change in the presence policy become a must: in the days of the "dedicated laboratory", the presence of all the students in the laboratory in order to do assignments was an obvious must. But in the situation when student by using the personal laptop can do all the assignments at any place, the requirement of 100% presence in the image processing laboratory became outdated. Then, the logistics of the image processing laboratory was reworked on the basis of cloud-based reporting: students can work at any place, by using specially prepared templates they prepare a report for each assignment, and send report by Gmail to the educator. Special efforts were made to make this logistics transparent and time-effective, as for student, as for educator, so that time needed to create, manage and grade the reports will be minimal.

In 2020 COVID-19 restrictions become a fact of life. Providing frontal lectures by ZOOM was found as a possible option. It was also found, that by using ZOOM, an educator can monitor students' activity during laboratory hours from a remote place nearly without changes, while the internet connection was stable.

Still, significant logistics changes were asked to be done to make a cloud-based approach practical. The rationale and details of logistics procedures that were used to provide the image processing laboratory by using cloud techniques during the last five semesters (part of them were under COVID-19 restrictions, part – hybrid) are discussed in the following sections.

Literature Review

Practical aspects of the laboratory's organizations were reported in many articles and discussed at many conferences.

Many educators discussed the ways how laboratory reports are created, stored, and graded. Writing reports on paper these days is considered an outdated and non-reliable practice. Many computer-based utilities can be used as a replacement of paper-based reporting. For example, well-known "Evernote" software was used to create electronic laboratory notebooks (ELN) (Walsh and Cho 2012). Another example is the use of Google Docs cloud service to effectively manage the data generated by many students. An important feature of this service is that files stored in the cloud are not processed by the local (client) computer, but by using cloud computing. This approach provides effective solutions for a number of data-management problems (Bennett and Pence 2011).

Some universities successfully provided a number of laboratories (or parts of them) remotely (Auer and Gallent 2000).

Specifics of the image processing laboratories – provided at the campus and by using cloud techniques were discussed (Rashid 2020).

COVID-19 situation stimulated modifications of laboratory logistics that were in use for many years, and these modifications were asked by the administration of universities and colleges to be done in an extremely short period of time – days. It can be expected that in the near future a large number of articles will discuss which changes were successful and which not.

Problems of laboratory organization, laboratory results reporting, and grading were intensively studied many years at Braude Academic College of Engineering (Kosolapov and Sabag 2009a, 2009b, 2015). This paper compares logistics used for the organization of the image processing laboratory in a "normal" semester, in a COVID-19 semester, and in "hybrid" semester (in which one part of the students were present at the campus, whereas another part of the students were permitted to work from their homes). Some elements of this time-effective cloud-based logistics were described before (Kosolapov 2021, 2020). This paper provides additional details concerning logistics modifications used in the "hybrid" semester.

Methodology

Logistics before COVID-19 Limitations

In a "normal" (before-COVID-19) semesters students of the Braude Academic College of Engineering, enrolled to the course "Image Processing", were expected to visit frontal lectures (albite physical presence on the lectures was not a must), and, additionally, participates in the laboratories provided in the class equipped with computers (physical presence in the laboratory during laboratory hours was a must). During the laboratories, students (organized by pairs) were asked to practically implement image-processing algorithms learned during frontal lectures by writing C and C++ code. Specifically, a PC with Windows 10 and a free community version of Visual Studio 2019 were used by students to write the code to be compiled as an "exe" file that can be run by any computer running Windows 10 OS. In addition to the requirement to write the code that can be compiled, linked, and executed, students were asked to prepare a PowerPoint presentation describing the code and the results obtained. To make grading of the reports simple, fair, and time-effective for the educator, for each laboratory assignment, the educator prepared a special template with clear items to be addressed. In a "normal" semester educator is physically present in the laboratory room, so that during the laboratory, students are permitted to ask the educator for help, and, in case of need, the educator provides additional explanations. When ready, students demonstrated the PowerPoint presentation and the working code to the educator and, in case of need, answered the questions asked by the educator.

The accepted grading policy was that if the presentation was good enough, and students reasonably answered the questions, they have got a high grade. As a backup, students E-Mailed the presentation and the code by using a special format developed specifically for that course. The goal of this special format was to implement time-effective logistics. Students were bounded by strict reporting rules that were explained at the first laboratory. Gmail based reporting rules are explained in the next section "Structure of Gmail based report.

Logistics under COVID-19 Limitations

From the spring semester of 2020 until the spring semester of 2022, Braude College was working under COVID 19 limitations. In the frames of these limitations, all laboratories (if possible) were requested to be executed by using ZOOM, and, then, some of the elements of the logistics that were used starting from 2007 became problematic.

After three days granted by the administration of the college for the "feasibility checks", it was decided, that this specific image processing laboratory can be provided remotely by using cloud-based services like ZOOM and Gmail. Other cloud-based services like MOODLE were found less attractive in this specific case.

Details of Cloud-based Logistics by Using ZOOM

Exactly, as in "normal semesters", some students in some specific situations were permitted to work from any place; now all students were allowed to work from any location, providing that a reliable Internet connection was available at that place. Practically, because of lock-down, students and the educator worked from their homes by using their personal computers. At due time educator starts the ZOOM session and permits to students enrolled to the laboratory to get in. To exclude non-pleasant situations of non-authorized access, waiting room access was enabled, so that the educator could see who was asking "to enter". At the beginning of the laboratory, the educator explains what must be done and explains details of the specific template. Considering that student's personal computers and laptops in most cases are not very powerful, and by taking into account, that Visual Studio requires significant resources, students were allowed to disconnect from ZOOM session, or at least disable their cameras. At any moment, students were able to reconnect to the ZOOM session and ask the educator for help. In case of need, the educator permit to the students to share the screen of their computers and demonstrate to the educator problem they revealed.

COVID and Hybrid Semesters: Changes in Physical Presence Policy

According to the college rules, the physical presence of the student in the laboratory provided in-campus is an academic must. However, starting from 2005, many students preferred to use their personal laptops instead of computers in the laboratory. It was found, that this practice has some advantages: for example, the laboratory room is less crowded during the laboratory. When a specific pair of students was ready to present PowerPoint presentation and working code, then this pair of students physically arrived to the laboratory room for regular grading procedure.

By using experience obtained during COVID-19 semesters, it was decided, that requirement of physical presence can be not strict as before. Then, in a hybrid semester students were provided an option –to be present in the class, or work from another place by using ZOOM. At any case, students were required to send the report by using Gmail based procedure described in the following sections.

Changes in the Grading Procedure

In the COVID-19 semesters, grading laboratory reports by direct interaction with students was found non-realistic, even by using ZOOM. Hence, the educator graded student's work by reading and evaluating reports only. To make grading fair and consistent, the educator created Excel files containing clear criteria for a fixed number of items to be addressed in the specific report. An example of those items will be described in the section "Example of Grading by Items". While grading the reports, the educator add points in Excel file and, in case of problems, lower the grades for the specific item and add a comment in the relevant cell. To make grading time-effective, numbered lists of typical errors were used – the comment refers to the number of the error – much less typing for the educator. Additionally, students were able to understand without interaction with the educator why their grade was lowered. In some situations, students were permitted to present an additional version of the report and improve their final grade.

Structure of Gmail Based Assignment Report

Sending a report by email looks like a simple procedure. However, if students send reports without a specific format, the educator will spend a lot of time sorting, managing, and grading those reports. This is why part of the time-effective logistics is a strict structure of the email fields. Long ago it was decided to use Gmail as a mail server for the developed then logistics. The reasons then were: Gmail was the first free cloud-based email server (that is, all emails were accessible from any computer), and from the early days, Gmail has had excellent sorting tools. A number of Gmail accounts were possible to create without problems. Hence, in order to prevent cross-talk between different courses, it was decided that every course, that will use a specific variant of this cloud-based logistics, will be operated by a dedicated Gmail account – with the different account name and different password.

Table 1 describes the structure of the Gmail-based report. Field "To" contain account name of the Gmail dedicated to this course. For security reasons, real name of the specific account will not be revealed here, hence "*" symbols are used to hide parts of the account name. Important to mention: this specific Gmail address is used for sending reports only. During the laboratory, students work by pairs. When one of the students sends a report to the educator, it is a strong requirement to fill "CC" field (carbon copy) by typing college' Email of the second student. Additionally, second student is asked immediately validate receiving this specific report, download all attachments and validate that they contain all materials required. This simple requirement effectively prevents “false” student’ claims that the report was send, but the educator claim that it was not sent. In this situation, an educator may ask the second student to send a “screenshot” of his/her email application.

Field “Subject” contains a specially designed E-Signature – a set of alpha-numeric tokens to be modified specifically for every assignment. In the frame of the Image Processing Laboratory, there are two types of assignments: Laboratory assignment and Micro Project assignment. Specifically, last semester there were 12 laboratory assignments and two micro-projects. The structure of the E-signature for the case of laboratory assignment is described in Table 2. The structure of the E-signature for the case of Micro Project is the same except token #3 – it was “MPYN” instead of “QR”, where Y was 1 for Micro Project 1 and 2 for Micro Project 2. N was a number in the list of Micro Project subjects.

Field “Text” was not used in the frames of this logistics. Educator was not expected to waste his/her time by reading “free text” written by students. But, in order to comply with Gmail security rules (Gmail without subject go to “Junk”), some text was asked to be added. For example: “Assignment 11 finished”.

The report and other files to be used for the grading are combined in the zip file having the same name as the “Subject” field. Specifically for the Image Processing course, files inside zip file can be used to recreate executable written by students. To do this, the educator must unzip the attachment, double-click the “sln” file, and then press the F5 button. In case a valid executable is not created, then the assignment is rejected. PowerPoint Report can be opened without the need to unzip zip file.

An important part of the grading is feedback – some remarks that the educator sends to the students. Again, being non-standardized, this feedback may quickly become time-consuming for the educator. In the frame of this logistics, the only possible feedback for the laboratory assignments that is sent from this Gmail account back to the students is “Assignment QR OK” or “Assignment QR wrong” (QR stands for the laboratory assignment number). Micro Project reports are not answered. Details of the feedback in this case will be discussed later. Reports containing Gmail that has wrong “Subject” (not in accordance with requirements) are ignored and never opened. Again, this Gmail is never used for time-consuming discussions. Details of time-effective grading and time affective appeals processing for the grades set by the educator will be discussed in the following sections.

Naming Rules for Laboratory Assignment

Additional important elements of the logistics are strict reports naming rules. The goal of these rules enables fast management of the reports sent by students. Table 2 contains the exemplary description of tokens (short set of letters and digits) used to name Laboratory Assignments. Important to understand, that ‘-’ character is used as a delimiter between tokens (See Table 1). Using delimiters significantly simplifies the search in Gmail.

Table 5. *Structure of the Gmail Based Assignment Report*

Gmail Field	Example	Comment
To	*ImProc*@gmail.com	Dedicated Gmail. Used for cloud-based reports only
CC	MosheX@ebraude.ac.il	College Email of the second student
Subject	ABCD-EFGH-QR-X or ABCD-EFGH-MPYN-X	E-Signature for Laboratory assignments - see Table 2 for details or E-Signature for Micro Projects
Text	Assignment 11 finished	Some text is a must for legal Gmail - to discard spam
Attachment	ABCD-EFGH-QR-X.zip or ABCD-EFGH-MPYN-X.zip	zip file must contain PowerPoint presentation having the same E-Signature name as a subject and at least the following files: *.h, *.cpp, *.sln, *proj. In case of need, BMP images are to be added.

In Table 2, one can see that the first token is ABCD –those four letters are to be replaced by the last four digits of the first student's ID. Full ID in Israel contains 9 digits, but for security reasons, only four last are used. It is the latest and not the first digits that are used, because they are more “random”. The second token EFGH contains four last digits of the second’ student ID. To prevent ambiguity, the rule is: ABCD < EFGH, hence it is clear which student is “the first” and which is “the second”. In the frame of this logistics student’ names are never mentioned in the reports. Hence, when grading the reports, the educator do not know who those students are, hence, who is “the first students” in this specific pair, and who is “the second” – has no influence on the grading.

Token #3 “QR” decodes the number of the assignment. Token #4 “X” encodes the number of the report’ version. Current policy is to permit a number of report’s versions. As a first step a pair of students send the report with X=1. In the case the report was found “correct”, they receive the feedback: “Report OK”. In case of problems, they can see errors in the dedicated Excel file. Then, students have an option to send an additional (corrected) version. For the first assignment 11 three versions were permitted to send. For other assignments, only two versions were allowed to send. It is clear, that with this “soft” policy, most of the grades will be maximal. It must be taken into account, however, that high grades were not granted “for free”, but after the hard work of the students.

Table 6. *Naming Rules for the Laboratory Assignment*

Token #	Token Template	Comment
1	ABCD	Four last digits of the first' student ID
2	EFGH	Four last digits of the second' student ID
3	QR	Number of assignment: 11,12,13,14 21,22,23,24 31, 41, 51, 52
4	X	Number of Laboratory Report version X = 1,2,3 for QR = 11 X = 1,2 for other assignments

Example of Grading by Items

Fair and consistent grading by reports only is always problematic. Hence, report templates contained a list of clearly defined items to be addressed in the report. Of course, details of those items were explained to the students at least twice (in the frontal lecture and in the laboratory). Exemplary details of "grading by items" are presented in Table 3.

In this specific example, pair of students is required to create the function "AddGrayRectangle". In the lecture, the lecturer explained the "blending technique" – how to add an object to the image while not exceeding byte ranges. Additionally, in the lecture concept of "clipping" was explained – what to do if the object to be added partly or in full is out of the basic image ranges. Students that did not understand those concepts will not be able to fulfill the requirements of the items 2 and 3 of Table 3. From the logistics point of view. An educator immediately (in seconds) will reveal if students understand the above concepts or not. Again, from the logistics point of view, an educator must not type long explanations of what was wrong: considering. That error of that type is a typical and "predictable" error; hence, this error is a good candidate to be included in the "list of errors", so that an educator must only add the number of this error in the list in the relevant cell of the Grading Excel File. It is clear, that creating "list of errors" is not a simple task, but over the years of using, this list became more stable. Additional important part of fair grading is that when the error is in the "list of errors", an educator lowers the grade in the same way for any pair of students. This, effectively, eliminates most of "appeals" for unfair grading.

One of the requirements is that students will add all files needed to recreate executable file that will create all requested images. However, opening the project, compiling it, and running the executable require some time – minutes. The requirement to add the code of the function "AddGrayRectangle" to the PowerPoint presentation enables to the educator to see the code immediately. It is assumed, that the educator is skilled enough to understand if the code good enough or not. In case the code is not in full accordance with the requirements, an educator marks the assignment as "having problems" and asks the relevant pair of students to rework the project. Obviously, in this case, there is no need to start the time-consuming process of testing the project for the current version of the report.

An important requirement was that created code really works – this requirement prepares students for the actual work in the industry – where an obvious requirement is that the "product must operate as described".

Important to understand, that described procedure of grading by items, does not require direct contact between students and the educator, and, thus, can be used as in "normal semester", as in "hybrid semester".

Table 3. *Example of Grading: Laboratory Assignment 11*

#	Item	Points
1	Put YOUR resulted image "grayImage11.bmp" *and add short comment what the educator is expected to see*	1
2	Put Relevant Profiles Here. *(to prove that image "grayImage11.bmp"* *was created as required)*	2
3	Code of the function "AddGrayRectangle" *With proper comments*	2
4	Proof that the function "AddGrayRectangle" works as described (use scientific tools)	2
5	Code of the "main" function	2
6	What did you learn?	1
	Total	**10**
A	Code cannot be compiled and run	-5
B	Not all the images created as required	-5

Results

Updated for the "hybrid" situation, ZOOM-based logistics was tested during the last two semesters. By comparing the level of students' presentations and the complexity of the code with those of "normal" semesters, COVID-19 semesters, and "hybrid" semesters, it can be stated that the level of the presentation and the level of the code were practically identical. However, considering the small number of semesters in each category, it is clear that no valid statistical analysis can be provided in that case.

Discussion

All modifications of cloud-based logistics were found reasonably time-effective from the educator's point of view. Typically, grading one assignment takes less than 1 minute if the report and code were found as "good enough". However, processing of "problematic reports" took more time – especially for explaining the errors. Hence, it was decided to immediately stop the checking process if serious problems with the presentation and/or code were found. In that case, rework of the report was requested. In order to prevent the unlimited number of "reworks", the number of reworks was set to 3 for the first assignment (to enable students to learn the level of requirements), but for the following assignments, the number of possible reworks was set to 2. It was assumed that after the second rework grade for the specific assignment will be less than maximal. However, most of the students quickly understand the meaning of this limitation, and, at the end, most reports have got maximal grades. At every semester, however, a number of students did not send all reports before the deadline, and, in that case, the final laboratory grade was significantly less than maximal.

Unfortunately, collecting students' opinion (students' feedback) about specific courses under COVID-19 restrictions become problematic, as practically, as ideologically – in the end, only a small number of students provided this feedback. Hence, this parameter cannot be used to evaluate the quality of the selected cloud approach. However, privately, after getting final grades, many students claimed that this specific laboratory can be provided by using cloud services.

Conclusions

Modified logistics of cloud-based image processing laboratory were found to be reasonably time-effective for the educator.

Cloud-based courses have some obvious advantages and some disadvantages. The educator cannot be aware that specific students really executed all laboratory assignments without significant external assistance. It was practically impossible to state if the work was equally distributed between both students of the specific pair.

Still, developed logistics can be considered as a preliminary prototype of a remote image processing laboratory. More R&D work must be done to arrive to statistically valid conclusions if a remote Image Processing laboratory can be good enough compared with a "regular" in-campus laboratory.

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