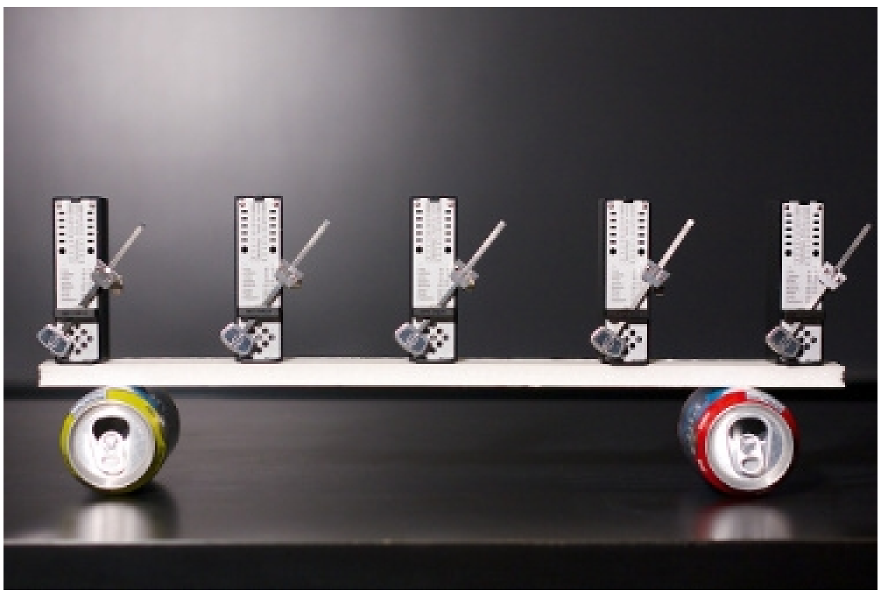
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Experimental Methods for Engineering Mechanics

Synchronizing images and loading measurements



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Abstract

The second module of the course *Experimental Methods for Engineering Mechanics* given at EPFL is centered around using DIC to track an elastomer sample under ramped tensile loading. The problem we encountered was that no option was available to synchronize the tensile machine and digital photographic equipment on a global timescale. This makes relating images to their respective Neumann boundary conditions (instantaneous tensile force deployed by the UTM) more difficult. Additionnaly, the camera Quantalux 2.1 MP Monochrome sCMOS Camera from THORLABS™used was set to snapshot at 30fps while the loading machine's firmware only allowed for 10hz measurements. This meant 3 unsynchronized images per loading case. This short work is a method to solve these two technical challenges.

UTM and Camera use

The experiment uses dynamic tensile loading from an initial displacement considered null ($x_0 = 0$) to a final displacement x_f of the supports in a time t_f.Ideally, in the digitally synchronized case, the recording starts at $t = 0$ and ends at $t = t_f$. Unfortunately, since this could not be done, the camera needs to be started by hand before the loading begins ($t_1 < 0$) and stop at some $t_2 > t_f$ in order to capture all the experiment. The first challenge is equivalent to finding the first and last image in which there is significant displacement. This is done by entering the .tif image concatenation file on ImageJ™which allows to smoothly browse through each. The transition between static and dynamic is grossly identified to a range of about 10 images by human effort. Then, the images are each marked with the *Line Tool* at the extremities of the supports 1 (the longer the line, the more easier it is to notice global movement). This final selection is then browsed until the line changes length. The same procedure is applied in the other direction (negative time increments) to find the end of the experiment. All the images before the identified start and after the identified end are deleted. If everything went smoothly the amount of images should be exactly three times larger than the force measurements.

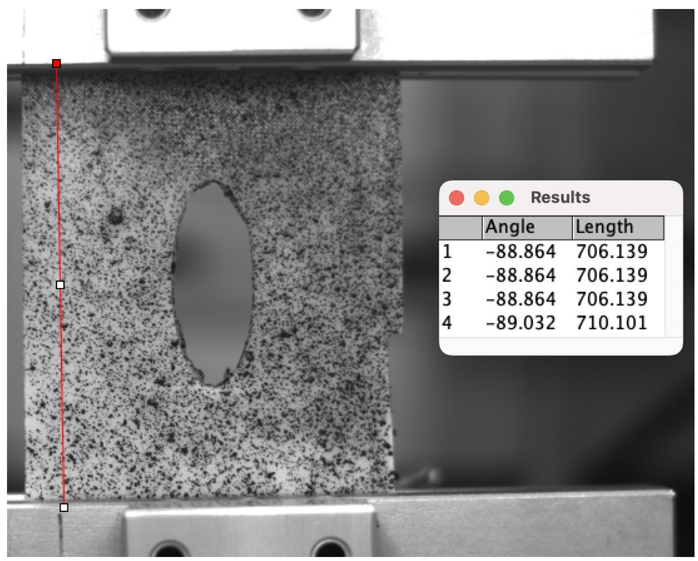
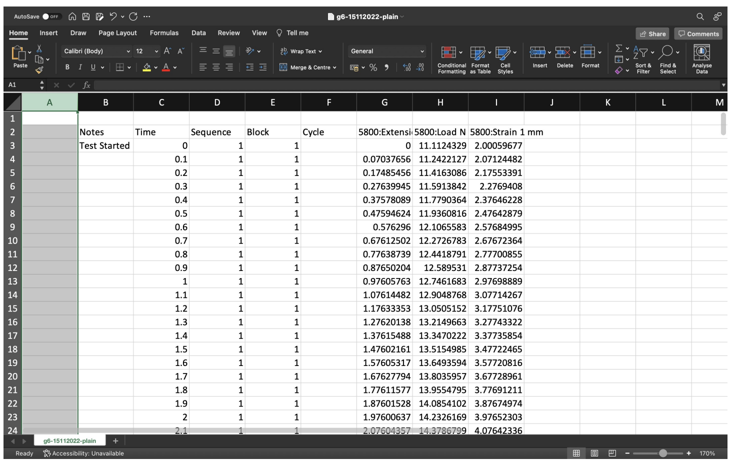


Figure 1: The *Line Tool* tracks the same two points on each image and allows to accurately measure the distance between them.

Excel interpolation method for larger data

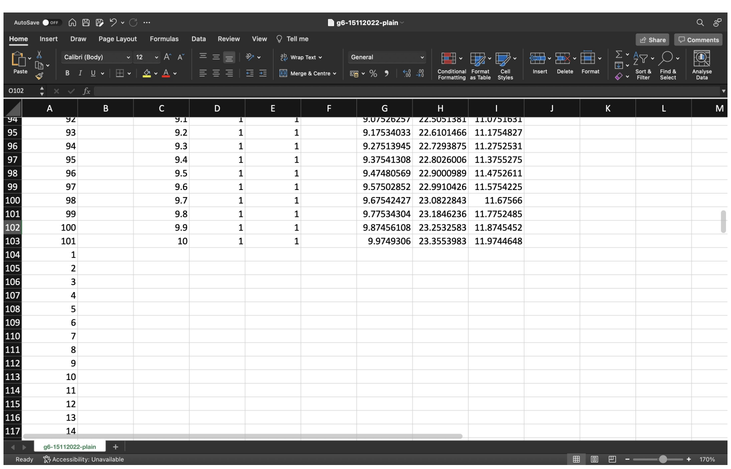
There are two ways of going about matching each image to its respective loading environment : either reduce the amount of images by picking one every three (or averaging) which can have an unpleasant impact on correlation when applying DIC or interpolate two points between each force measurement. The later is done with equidistant linear interpolation which is acceptable for slow-dynamic or quasi-static loading settings (our case). The practical problem of applying two interpolation in between every points is quite tricky. In the interest of time for the reader, we provide a way of doing this on excel without spending four hours per measurement clicking away. Our data was made of 101 force measurements (10 second experiment) which means our objective was ending up with 301 points of data (since there are no interpolations after the last point). Let N be the total number of experimental values (in our case N=101).

1. Open the force Data and insert a blank column on A.



	A	B	C	D	E	F	G	H	I
1									
2		Notes	Time	Sequence	Block	Cycle	5800:Extensi	5800:Load N	5800:Strain 1 mm
3		Test Started	0	1	1		0	11.1124329	2.00059677
4			0.1	1	1		0.07037656	11.2422127	2.07124482
5			0.2	1	1		0.17485456	11.4163086	2.17553391
6			0.3	1	1		0.27639945	11.5913842	2.2769408
7			0.4	1	1		0.37578089	11.7790364	2.37646228
8			0.5	1	1		0.47594624	11.9360816	2.47642879
9			0.6	1	1		0.576296	12.1065583	2.57684995
10			0.7	1	1		0.67612502	12.2726783	2.67672364
11			0.8	1	1		0.77638739	12.4418791	2.77700855
12			0.9	1	1		0.87650204	12.589531	2.87737254
13			1	1	1		0.97605763	12.7461683	2.97698889
14			1.1	1	1		1.07614482	12.9048768	3.07714267
15			1.2	1	1		1.17633353	13.0505152	3.17751076
16			1.3	1	1		1.27620138	13.2149663	3.27743322
17			1.4	1	1		1.37615488	13.3470222	3.37735854
18			1.5	1	1		1.47602161	13.5154985	3.47722465
19			1.6	1	1		1.57605317	13.6493594	3.57720816
20			1.7	1	1		1.67627794	13.8035957	3.67728961
21			1.8	1	1		1.77611577	13.9554795	3.77691211
22			1.9	1	1		1.87601528	14.0854102	3.87674974
23			2	1	1		1.97600637	14.2326169	3.97652303
24			2.1	1	1		2.07604357	14.3786799	4.07642336

2. Enumerate every cell in the blank column starting from the first measurement (in our case from 1 to N=101). Copy the range of cells from 1 to N-1 and paste them 2 more times in the column-A successively (column-A should look like 1,2,...N,1,2...N-1,1,2,...N-1). This should yield two set of blank rows enumerated from 1 to N-1.



	A	B	C	D	E	F	G	H	I
94	92		9.1	1	1		9.07526257	22.5051381	11.0751631
95	93		9.2	1	1		9.17534033	22.6101466	11.1754827
96	94		9.3	1	1		9.27513945	22.7293875	11.2752531
97	95		9.4	1	1		9.37541308	22.8026006	11.3755275
98	96		9.5	1	1		9.47480569	22.9000989	11.4752611
99	97		9.6	1	1		9.57502852	22.9910426	11.5754225
100	98		9.7	1	1		9.67542427	23.0822843	11.67566
101	99		9.8	1	1		9.77534304	23.1846236	11.7752485
102	100		9.9	1	1		9.87456108	23.2532583	11.8745452
103	101		10	1	1		9.9749306	23.3553983	11.9744648
104	1								
105	2								
106	3								
107	4								
108	5								
109	6								
110	7								
111	8								
112	9								
113	10								
114	11								
115	12								
116	13								
117	14								

3. For now, we only focus on the extension, load and strain interpolations (3 last columns). The first set of blank rows. The interpolation between each point is linear and returns two additional values. Let F_i and F_j $(i < j)$ be two force measurements with F_i1 and F_i2 two interpolations :

$$F_{i1} = \frac{F_j - F_i}{3} + F_i \qquad\qquad F_{i2} = 2\frac{F_j - F_i}{3} + F_i$$

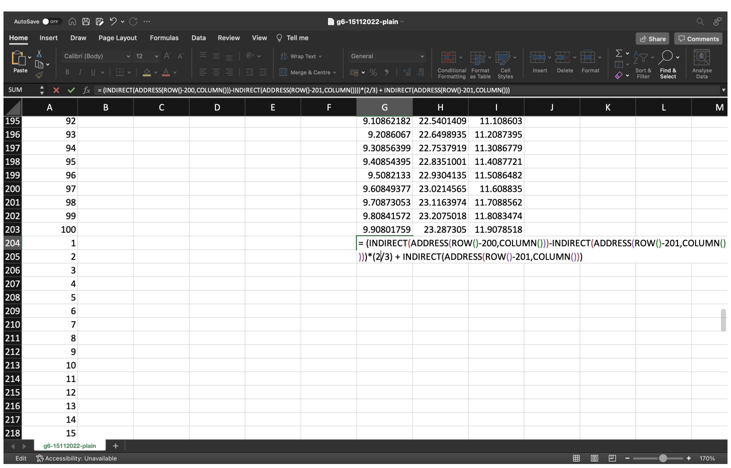
The goal is to apply this to excel without doing too much work. The first enumerated empty row set works as the collection of F_{i1}'s and the second of F_{i2}'s. The 3 cells corresponding to force measurements of the first blank row of the first empty row set are filled with the following Excel code :

= (INDIRECT(ADDRESS(ROW()-N+1,COLUMN()))-INDIRECT(ADDRESS(ROW()-N,COLUMN())))*(1/3) + INDIRECT(ADDRESS(ROW()-N,COLUMN()))

The remaining N rows of the empty set are filled (using the fill handle on the right bottom cell corner) for each column.The same procedure is done for the second empty set. The 3 cells corresponding to force measurements of the first blank row of the second empty row set are filled with the following Excel code :

= (INDIRECT(ADDRESS(ROW()-2N+2,COLUMN()))-INDIRECT(ADDRESS(ROW()-2N+1,COLUMN())))*(2/3) + INDIRECT(ADDRESS(ROW()-2N+1,COLUMN()))

The remaining N rows of the empty set are filled (using the fill handle on the right bottom cell corner) for each column.

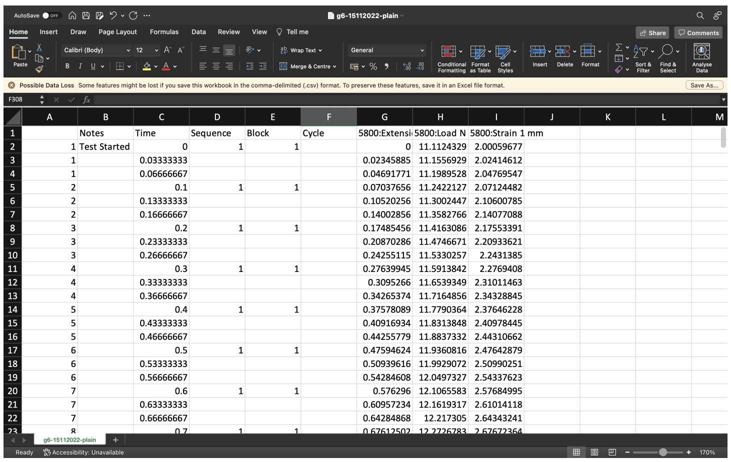


4. Now that all the interpolations are set, the only thing left to do is order everything into place. For this, save a copy of the file as .csv and close the active .xlsx file. Open the .csv copy with excel again (this rids the file of any formulas and only keeps the numerical values). Put the active cell cursor in the A column and use *Sort & Filter/Sort A to Z* to put every interpolated value into place.

5. The table is almost done and the only thing left is adding the time values for each interpolation. Since each point is defined as equidistant, the time step is 1/30th of a second. Select the second (empty) time row and input :

   $=$ **INDIRECT(ADDRESS(ROW()-1, COLUMN())) + 1/30**

   The only thing left to do is fill every cell from that cell onward and call it a day. Check that there are 3N-2 points of data.



	A	B	C	D	E	F	G	H	I
1		Notes	Time	Sequence	Block	Cycle	5800:Extensi	5800:Load N	5800:Strain 1 mm
2	1	Test Started	0	1	1		0	11.1124329	2.00059677
3	1		0.03333333				0.02345885	11.1556929	2.02414612
4	1		0.06666667				0.04691771	11.1989528	2.04769547
5	2		0.1	1	1		0.07037656	11.2422127	2.07124482
6	2		0.13333333				0.10520256	11.3002447	2.10600785
7	2		0.16666667				0.14002856	11.3582766	2.14077088
8	3		0.2	1	1		0.17485456	11.4163086	2.17553391
9	3		0.23333333				0.20870286	11.4746671	2.20933621
10	3		0.26666667				0.24255115	11.5330257	2.2431385
11	4		0.3	1	1		0.27639945	11.5913842	2.2769408
12	4		0.33333333				0.3095266	11.6539349	2.31011463
13	4		0.36666667				0.34265374	11.7164856	2.34328845
14	5		0.4	1	1		0.37578089	11.7790364	2.37646228
15	5		0.43333333				0.40916934	11.8313848	2.40978445
16	5		0.46666667				0.44255779	11.8837332	2.44310662
17	6		0.5	1	1		0.47594624	11.9360816	2.47642879
18	6		0.53333333				0.50939616	11.9929072	2.50990251
19	6		0.56666667				0.54284608	12.0497327	2.54337623
20	7		0.6	1	1		0.576296	12.1065583	2.57684995
21	7		0.63333333				0.60957234	12.1619317	2.61014118
22	7		0.66666667				0.64284868	12.217305	2.64343241
23	8		0.7	1	1		0.67612502	12.2726783	2.67672364

The images and force/strain/displacement measurements can now be linked on a 1 to 1 basis for any further digital processing (DIC for ex).