# **FastDVC** Simple Tutorials<sup>[1]</sup>

## - Base Theory

Based on the principle of digital image correlation, for details, please refer to the paper<sup>[2,3]</sup> and related papers involved.

And related papers involved:

$$\varepsilon_{z} = \frac{\sqrt{2}}{3} \times (\varepsilon_{x} - \varepsilon_{y})^{2} + (\varepsilon_{y} - \varepsilon_{z})^{2} + (\varepsilon_{z} - \varepsilon_{x})^{2} + \frac{3}{2}(\gamma_{xy}^{2} + \gamma_{yz}^{2} + \gamma_{zx}^{2})$$

$$\varepsilon_{y} = \varepsilon_{1} + \varepsilon_{1} + \varepsilon_{1} = \varepsilon_{x} + \varepsilon_{y} + \varepsilon_{z} \cdots \cdots (6.2) + \varepsilon_{z}$$

式中, $\varepsilon_x$ 、 $\varepsilon_y$ 、 $\varepsilon_z$ 、 $\varepsilon_x$ 、 $\varepsilon_x$ 、 $\varepsilon_y$ 、 $\varepsilon_z$ 分别为x、y、z方向的 应变和剪应变。 $\downarrow$ 



Fig. 3 Labelled photograph of the Laboratoire 3SR X-ray scanner, with background faded out for clarity

# 二、User Manual

## 1、How do I get it?

FastDVC download link (Zenodo): http://doi.org/10.5281/zenodo.3610829

Open the software requires a unique key, a computer generates a unique key, you need to provide the installation software: host name and CPU ID.

As shown below: In the cmd or shell, type: "wmic cpu get processorID" to get the relevant hardware information.

👱 系統				- 🗆 X
← → ~ ↑ ₹ > ±	空制面板 → 系统和安全 → 系统			✓ ひ 捜索控制面板 タ
控制面板主页	查看有关计算机的基	本信息		0
💡 设备管理器	Windows 版本			
💡 远程设置	Windows 10 专业版			
💡 系统保护	© 2019 Microsoft Cor	poration。保留所有权利。	M/ir	ndows10
💡 高级系统设置		•		10010310
	系统			
	处理器:	Intel(R) Core(TM) i7-6700 CPU @ 3.40GHz 3.40 GHz		
	已安装的内存(RAM):	20.0 GB (19.9 GB 可用)		
	系统类型:	64 位操作系统,基于 x64 的处理器		
	笔和触控:	没有可用于此显示器的笔或触控输入		
	计算机名、域和工作组设置			
	计算机名:	XTZ-01708031054		●更改设置
	计算机全名:	XTZ-01708031054		
	计算机描述:			
1				
C:\WINDO	OWS\system32\cmd			
Microsoft ¥	/indows 「版本 :	10. 0. 18362. 175]		~
(c) 2019 Mi	icrosoft Corpor	ration。保留所有权利。		
	reresere corpor			
C.) II) A.				
C:\Users\Ad	uministrator/wi	ac cpu get processoriu		
Processoria	uLL截图(W)			
BFEBFBFF000	D506E3			
C·\Heene\&	-			
C. (USELS (AU				

Generate a unique key, for example:

1c9c8eeab2eced71a0600acee2b6ab0dcf1e8787d29d701d0f804cdb8xxx, Open Licene path to open it.

▲ DVCPassword –					$\times$
	Fa	astDVC			
licence C:\Users\Administrator\Desktop\lincese.mat					
password					
	Licence		O Oper	n DVC	

JVC				- 🗆 X
Pre-processing Strai	in View Plot			צי
FastDVC or	nly for personal and resercl	h	resize 1.0 S	plice Ca-Re result
Ca_File		Data Cut	Verify Accuracy jobs 4	<ul> <li>Splice</li> </ul>
Re_File		O DO DVC !	O Act Parallel	
Save				⊖ refresh
Set parameter	Set PSO	command windows		
search radius 10	Pso.c1 1.5	% This is a Free ver % this version is fre	rsion e for 1 year	
sub radius 20	Pso.c2 1.5	% If you have any que % Please contact m	uestion about DVC	
grid 10	Pso.maxgen 100	% algorithm based of	on Improved IC-GN,	
smooth radius 5	Pso.maxgen_part_ra 0.5	% local MaxStrain >	20%,	
memory Cut 1	Pso.size 20	% big strain can use %%%%%%%%%%%%%%%	e Splice module %%%%%%%%%%%%%%%%	
XYZ Cut 0	Pso.size_part_rat 0.2	% Ca_File load DVC % DVC.Dx, DVC.Dy	C.mat structur of DVC.ma , DVC.Dz, DVC.ZNCC	at :
amend radius 5	accuracy norm	% almost MATLAB f	fucntions can be used	
IC-GNtimes 10	norm ^			~
	lingii v	Load txt Codes		O DO Coders

If the password is wrong then maybe like those:

▲ DVCPassword			—		×	
FastDVC						
licence	licence C:\Users\Administrator\Desktop\licence.mat					
password		11		]		
	O Licence	•	Oper	DVC		

## 2、 DVC Pre-processing

#### 2.1 Segmentation threshold selection



Chose the save path use [Save] Reference images [V0] and Current images [V1] file path (note: Currently only supports .tif format images, non-RGB3 layer data, preferably uint8 format, reducing memory requirements in big data). The threshold is selected to adjust the matching of the two CT data on Z, reducing the post-DVC calculation pressure and improving the accuracy.

You can choose the segmentation threshold at the beginning, such as "0,1" (only this form, two values + one comma in the middle, and must be in English), enter [Try Thod], Choose the appropriate threshold based on the most prominent and stable material in the results. As shown in the figure below, this material is a mixed soil containing clay and quartz particles, while quartz particles are relatively stable.



According to the cross-sectional view of the above figure, it can be confirmed that the approximate gray value range of the quartz particles (not very accurate) is "120,200", and the following figure is obtained. The threshold range is continuously adjusted according to the comparison effect of Fig. subplot(2,3,2-3) and Fig. subplot(2,3, 5-6) until it is reasonable. until.



#### 2.2 Z-axis content component matching and selection

When the threshold is selected OK, enter [Z content] Calculate the Z,axis content distribution of the selected threshold, and will generate content.mat and Z.mat<sub>o</sub> Then enter [Plot] to plot curve about distribution of the content. If the sample is reversed during the CT scan, you must in the [overtun] input "1" (Synchronous real-time loading generally does not occur in this situation ).



Change the value [Z offset] to match the two curves as much as possible.

Input the values **[**Z range**]** to select the range of layers you need to calculate. If you want to calculate most range of the sample, you may input big value, just like bellow Fig.



#### 2.3 XY Angle

Also to reduce the calculation error, angle matching (Note: If it is real-time synchronous loading, set to 0, but you must click [Try\_Angle] (0-360°) to generate the corresponding setting parameters). If the sample is reversed during the CT scan, you must in the [Mirror] (0 not-overtun, 1 overtun) input "1". Get reasonable angle matching by constantly comparing results. As shown below:

Note:

1)If the original CT picture is not centered, use [Ox, Oy] to adjust

2) If the size of the before and after tif images is different, you need to adjust [Size]

You can directly adjust the center offset parameter and the Size parameter by clicking [Try size]



#### 2.4 Generate matrix.mat

The matrix can be generated when all the previous parameters are reasonable. But need to pay attention to: 1) If the CT matrix is large (compared to the computer's memory), you can choose the right one. [resize], like "0.5", the initially 1000^3 change to 500^3;

2) If the calculated area is small, you can choose [Size] value to cut matrix data, and you can enter [Try

size] value to determine the best value  $_{\circ}$ 

When all the parameters are OK, then enter [Generate] to generate Date 'V0.mat' and "V1.mat".



## **3 DVC Calculation**

### **3.1 Setting Parameters**

Set [Ca File] and [Re File] (Open Data V0.mat and V1.mat) and [Save] path.

1) [search radius] Unit is a voxel, Search windows is  $(2*s+1)^2$ . Adjust the appropriate value with the [Estimation] module, which is generally slightly larger;

2) [sub radius] Unit is a voxel, Sub windows is (2\*M+1)^2, small strain big M, big strain small M;

3) [grid] Calculation interval;

4) [smooth radius] It is the Gaussian filter radius. Generally, some noise will appear in the CT scan, and it will be preprocessed. If it has been processed, you can select a smaller value;

5) [memory Cut] Used to reduce the memory requirement operation. When the data is large (for example, greater than 500^3), you can select "3". When the data is small, you can select "1". Generally, you can select "2";

6) [XYZ Cut] It can be used when the calculation memory is small but the calculation data is large. For example, select "2" for  $2^3=8$  division;

- 7) [amend radius] useless;
- 8) [IC-GN time] Set the maximum number of algorithm iterations, the default is "10";
- 9) [ZNCC\_thed] if the zncc < ZNCC\_thed, those points need to be revised;
- 10) [accuracy] Current support: normal accuracy "norm" and high precision "high";

DVC		-	_		×
Pre-processing Strain View Plot					3
FastDVC         only for personal and reserct           Ca_File         C:\Users\\cs\Desktop\DVC_sample\大变形\V1-0.1.mat           Re_File         C:\Users\\cs\Desktop\DVC_sample\大变形\V0.mat	DO DVC !	Splice Ca-Re re O Splice	esult		
Save C:\Users\\cs\Desktop\新建文件夹\	command windows			⊖ refre	esh
Set parameters       Show Data         search radius       10       amend radius       5         sub radius       20       IC-GNtimes       10         grid       10       ZNCC_thed       0.7         smooth radius       5       accuracy       high         memory Cut       1       norm	% This is a Free vers % this version is free % Support Deadline % If you have any qu % Please contact me % algorithm based of % Please take part in % local MaxStrain >2 % big strain can use %%%%%%%%%%%%%%%%% % Ca_File load DVC % DVC.Dx, DVC.Dy, % almost MATLAB ft % delete above text is Load txt Codes	sion for 1 year 2020-1-1 ! lestion about DVC a ! n Improved IC-GN, n QQ: 544465573 20%, Splice module %%%%%%%%%%%%%% .mat, structur of DVC.mat: DVC.Dz, DVC.ZNCC ucntions can be used !		) Coders	∧

#### **3.2 DVC Calculation**

Note: When performing calculations, be sure to select **[Parallel]** first, according to the number of cores of your own CPU, otherwise it will start too many cores and take up unnecessary memory (sorry: this bug is not solved yet). Turn off parallel calculation when the **[jobs]** value is "0-1".

1) [Data Cut] : If you input [XYZ Cut] like "2", then enter [DO DVC !] and it will generate those data like :



2) [Estimation] : At the before of main DVC calculation, you need to adjust the [search radius] value to estimate the search radius by the Fig results.



3) When those parameters are all setting OK, [Estimation] and [Data Cut] both be cancel, and enter [DO DVC!]. There will show the important messages in [command window] during calculating process. As a result there will generate DVC.mat, if the [Data Cut] is not 1 or 0, there will generate DVC\_sub Data just like:

12	> DVC_Sub
	名称
	DD_xy_[1_1_1]
	1_1_2] DD_xy_
	🗎 DD_xy_[1_2_1]
	1 DD_xy_[1_2_2]
	1 DD_xy_[2_1_1]
	1 DD_xy_[2_1_2]
	1 DD_xy_[2_2_1]
	🗎 DD_xy_[2_2_2]

- 4) [jobs] : The best value is CPU cores;
- 5) [Splice] : It is a little complex, it will be introduced in the future.

#### 3.3 Data Editing

If you need correction or other operations on the calculation results, you can use the secondary editing function, which can execute most of the MATLAB's own functions and your own code, but you need to pay attention to the fact that the "%" symbol cannot appear in the code. Not solved yet).

1) If there is a well-written module code that can be saved as a TXT document (only TXT is supported), you can enter [load txt code] to load your code, then you can modify in [command window];

2) Before you enter [Do codes], you must enter [Ca\_File] to load DVC.mat. Because the default is to edit the calculation result DVC.mat data, the struct of DVC.mat are: DVC.Dx, DVC.Dy, DVC.Dz, DVC.ZNCC<sub>o</sub>

## 4. Strain

承 Strain	_	×
Data C:\Users\Administrator\	Deskto	p\try-0-12\DVC.mat
smooth radius 5	grid	5
Gaussian 2 variance	cpu	4
Strain Interp3		O Parallel

The stain method base on  $paper^{[5]}$ .

- 1) [Data] : Choose the result data DVC.mat;
- 2) [grid] : The grid must be same with DVC's grid, otherwise it wrong !
- 3) [smooth radius] : General, you can choose is "5" or "10";
- 3) [Gaussian variance] : General, you can choose is "1-3";
- 4) When all the parameters setting OK, enter [Strain] then will generate data:

Data	explain
*_*_para	Least Squares Method for Solving Fitting Parameters
DVC_Dx/Dy/Dz	Displacement field in x, y, and z directions before smoothing
DVC_R_D1/D2/D3	stress $\sigma_1, \sigma_2, \sigma_3,$
DVC_R_Dts	Total displacement field $t_s = \operatorname{sqrt}(Dx.^2+Dy.^2+Dz.^2)$
DVC_R_Ds	Equivalent strain
DVC_R_Dv	Body strain $\sigma_v$
DVC_R_Dx/Dy/Dz	Smoothed displacement field of x,y,z direction
DVC_R_Dxx/Dyy/Dzz	Strain field in the x, y, z direction $\sigma_x$ , $\sigma_y$ , $\sigma_z$
DVC R Dxy/Dyz/Dzx	Shear field strain $\sigma_{xy}, \sigma_{yz}, \sigma_{zx}$

6) If you need to interpolate the strain result to the original matrix size, you can select the [Interp3] function, but at this time [Data] must select a result of the current [Stain]. If the data is large, the memory is tight.

## 5. View Plot: Post Processing

CutSave		_		×
Post Processing O Date E:\CT_data\深圳残积土\	DVC_SZ_0_4_8_12_16	%\DVC_resul	t\0_4%\Par	
Rsize 1	Boundary Co	olormap E	Background	I
x1 30 y1 15 z1 12	cyan yellow A pa	jet arula 🔨	0.5	
x2 30 y2 15 z2 12	magenta jet cyan hs red ✓ ho	t sv ot	ingrit 1	
Limit_min n Limit_max n	title this is	s an example		
◯ CutShow ◯ Save	cylinder Cut rad	lius 1		
percenta	age 🔲 XY Cut		soFace	
command window				
% Edit Data is <sup>«</sup> V" (Please delete text ! )				^
				Υ.

1) Choose the Strain result data, just like Ds.mat. Cut values x1, x2, y1, y2, z1, z2, you can enter [CutShow] then to see the figure to adjust the best values. At the same time, it can generate the Cut result data like Ds\_Cut.mat, this data can be used to [Iso Face].



The [Limt\_min] and [Limt\_max] can choose the show range, If you enter string(like "n"), it will be show all range value.

2) [Save] can save the [Cut Show] data to tif image, those images can be edit or show by other sorftware, like Avizo.

3) [IsoFace] : You can set [Boundary], [colormap], [Background] and [light] to show volume data, and

## the [title] add the title of fig. [percentage] XY Cut];



In the process of calculating the shear band, the connectivity index of the shear band can be calculated simultaneously. (The connectivity index is in the range [0,1]. When the shear band is completely connected, the connectivity index is 1, and when the ideal is completely discretely isolated, it is close to 0).

If you need to edit the volume data, you can directly perform data operation in the [Command Window]. The operable data is "V", and the format is the same as the [DVC] module.

# 参考文献:

[1] Li C, Shu R. Accurate and simple digital volume correlation using pre-interpolation. http://doi.org/10.5281/zenodo.3600641: Zenodo, 2020.

[2] 潘兵, 王博. 数字体图像相关方法研究进展[J]. 科学通报, 2017, (16):1671-1681.

[3] 苏勇, 张青川, 伍小平. 数字图像相关技术的一些进展[J]. 中国科学:物理学 力学 天文学, 2018, v.48(09):29-53.

[4] Alikarami R, Andò E, Gkiousas-Kapnisis M, et al. Strain localisation and grain breakage in sand under shearing at high mean stress: insights from in situ X-ray tomography[J]. Acta Geotechnica, 2014, 10(1):15-30.

[5] 潘兵,谢惠民. 数字图像相关中基于位移场局部最小二乘拟合的全场应变测量[J]. 光学学报,2007, 27(11):1980-1986.