DT-FOF-07-2020
Assembly of micro parts (RIA)

TINKER

FABRICATION OF SENSOR PACKAGES ENABLED BY ADDITIVE MANUFACTURING

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= Deliverable D6.4 =

Prototype of TINKER platform including closed loop error compensation

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Executive Summary

In this deliverable, the setup of the TINKER platform with the closed loop error compensation is described as well as results after implementing that setup.

Closed loop error compensation and primary interoperability structure for inkjet processes in the RADAR Tinker platform are described including prototype description and workflow of the pilot line.

The ML models are incrementally trained using the data coming from the pick and place machine.

For gap filling process, bitmaps are generated along with the locations of the two substrate fiducial points in pixel coordinates for correct alignment with the NOTION printer. For conductive circuit (DC layout) printing, bitmaps are generated along with the locations of the four chip fiducial points.

After inkjet printing at NOTION, overprinted PCBs (Printed Circuit Boards) are sent to BESI for 3D inspection with their optimized 3D metrology. By this step, the error compensation loop is closed, and another compensation step is initialized again if needed based on inspection results.

Based on inspection results, some problems occurred due to alignment problems and manufacturing residues. DC layout printing experiments suffered more, for example. Printing the dielectric base of the conductive circuit exposes the problem which is the ink already hits the bare die edges.

A cloud server is set by PRO to facilitate the transfer of data among all partners of the TINKER pilot line. All data generated are uploaded to the cloud server using a standard naming convention for readability and smooth workflow.

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1. Introduction

The vision of TINKER is to provide a new cost- and resource efficient pathway for RADAR and LIDAR sensor package fabrication with high throughput up to 250units/min, improved automation by 20%, improved accuracy by 50% and reliability by a factor of 100 to the European automotive and microelectronic industry via additive manufacturing and inline feedback control mechanisms. Autonomous driving and self-driving cars represent one prominent example for the use of microelectronics and sensor, most importantly RADAR and LIDAR sensors. Their respective markets have a big potential, e.g., it is estimated that the market size of LIDAR in automotive will double itself in the next two years (within 2020 to 2022).

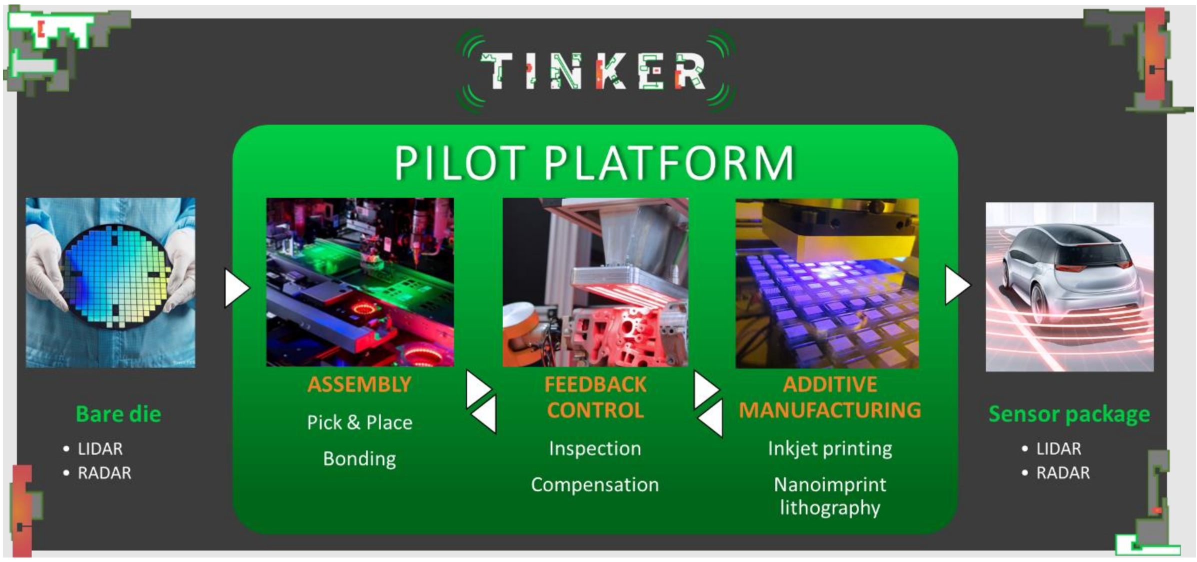


Figure 1: TINKER overview

The public awareness and the industrial need for further miniaturization of such sensor packages is the main driver of ongoing efforts in the automotive sector to be able to integrate such devices into the car body like in the bumpers and head lamps instead of attaching them (e.g., on top of the car in case of LIDAR device). Safety (for the driver and others) is the most important key aspect of the automotive sector. Therefore, high-value and high-performance RADAR and LIDAR systems are required for advanced driver-assistance systems (ADAS) as well as robotic cars. Current bottlenecks are the relatively large size of such sensor devices, their weight and power consumption. Since these factors are highly limited within cars, further miniaturization and improving functionality and efficient use of resources is highly demanded.

1.1. Description of deliverable

Functional prototype of TINKER pilot, deriving from prototypes for placement (D3.1, 4.1 and 5.1 and 5.4). Closed loop error compensation between devices. Interoperability established between the single TINKER pilot parts.

2. Results and Discussion

2.1. Prototype description

2.1.1. Pick and Place System

The feedback loop starts with the pick and place process that takes place at BESI as well as the post inspection of the bonded PCBs. The post inspection data are stored in a cloud server that can be accessed by all partners. Moreover, the loop is closed at BESI where the corrected PCBs are inspected to check the quality of the inkjet-printed PCBs and whether they are still defective.

The inspection data consist mainly of high resolution 2D monochrome images and 3D depth maps of the substrates after curing the adhesive. The following figure shows a sample of the inspection data.

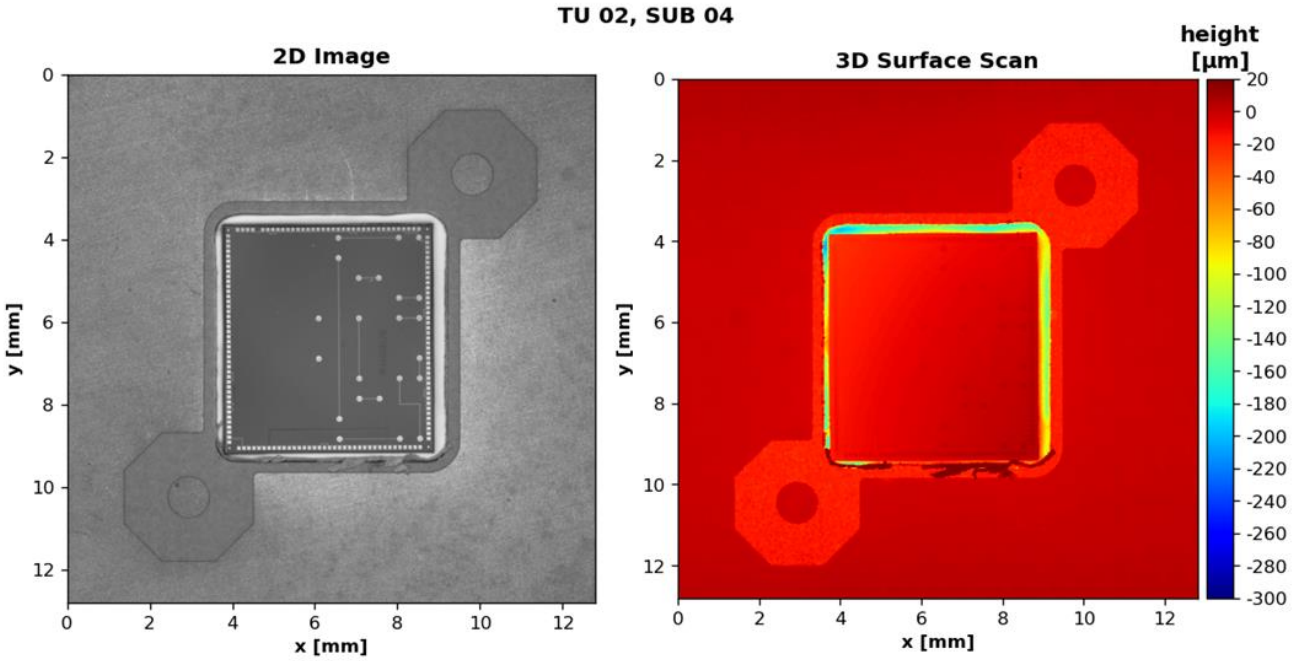


Figure 2: A sample from the inspection data of the substrates after curing.

2.1.2. NOTION Printer System

As of 31st of March 2023, the inkjet printer has been assembled and the commissioning of the printer is in progress. The electrical components have been checked and are functioning properly. Technical details and specification of the printer are described in the Deliverable **D5.5 Pilot line with inkjet system**

Due to the delays with the assembly of the printer it was decided that the laser sinter trials, which should be currently done in the printer, are currently ongoing at FORTH as a contingency plan. For this reason, it was now necessary to shift the laser integration which is expected in October 2023 to avoid interruption of the ongoing laser experiments and therefore lose further time. A later integration is expected not to cause any problems. Also, it does not make any difference now since TINKER platform is a delocalized pilot line and the sample geometry allows for subsequent sintering.

2.2. Setup of the closed loop error compensation

The closed loop error compensation scheme is shown in the following figure. It consists of several blocks; first, the pick and place system at BESI (deliverable D4.1); second, the feedback software developed by PRO; finally, the Notion Printer system (deliverable D5.5). The aim of the feedback loop is to be integrated inline the fabrication step of the Tinker platform. Moreover, it aims to repair the defects that might occur during the fabrication processes due to inaccurate input parameters or faulty machine behaviour. The following concept of the closed error compensation loop in figure 3 is to be applied to the Tinker platform of inkjet printing-based fabrication processes that are gap filling/correction and DC layout printing which take place as part of the RADAR use case. The printing of waveguide antennas is not part of the closed loop since here the relevant part is the inner 3D-geometry, especially the edge angle of the antenna’s walls. However, a deviation in the wall angle at a particular printed layer cannot be characterized properly until it was already overprinted with additional layers. But the overprinted layers already prohibit a correction of the observed layer and consequently there is nothing to inspect and correct for during the printing process. Moreover, the UV curing sensor is only used for optimizing the curing parameters which would be directly used henceforth. Therefore, including the UV curing sensor in the closed error compensation loop is not needed. Thermography inspection has proven to be inadequate because the thermal signal has a very poor condition as stated in D4.1. Moreover, it was not possible to find proof for the feasibility to check the quality of the connection of the conductive paths. That is why thermography inspection is not part of the closed loop as well.

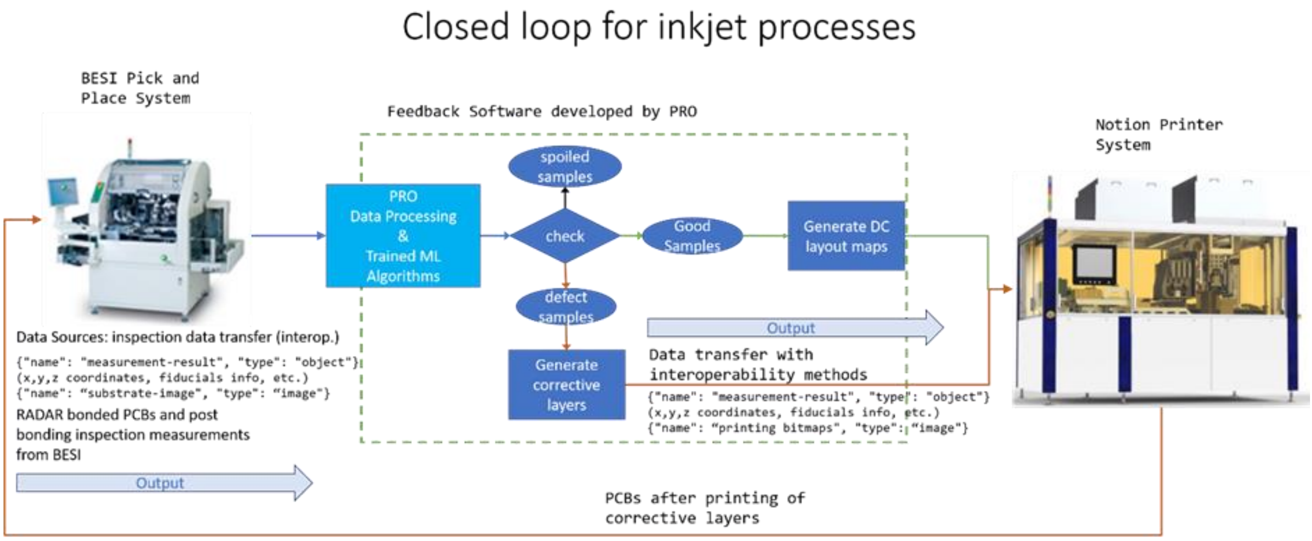

Closed loop for inkjet processes
BESI Pick and Place System
Feedback Software developed by PRO
Notion Printer System
PRO Data Processing & Trained ML Algorithms
spoiled samples
check
Good Samples
Generate DC layout maps
defect samples
Generate corrective layers
Output
Data transfer with interoperability methods
{"name": "measurement-result", "type": "object"}
(x,y,z coordinates, fiducials info, etc.)
{"name": “printing bitmaps", "type": “image"}
Data Sources: inspection data transfer (interop.)
{"name": "measurement-result", "type": "object"}
(x,y,z coordinates, fiducials info, etc.)
{"name": “substrate-image", "type": “image"}
RADAR bonded PCBs and post bonding inspection measurements from BESI
Output
PCBs after printing of corrective layers

Figure 3: Closed loop error compensation workflow integrated with the RADAR TINKER platform.

2.2.1. Data Processing and Models Training

The error compensation algorithms developed in T4.2 and T4.3 by PRO aims at processing the data received from BESI and then modelling the relation between the input 2D images of the substrates and the corresponding 3D depth maps. Due to the slight rotation of the bare-die inside the cavity, both 2D images and 3D depth maps were counter rotated to compensate for the die rotation. Then, they were cropped from the centres of the fiducial points. Finally, the high resolution 2D images are resized to match the size of the 3D depth maps. After processing the data, they were used to train deep learning-based models. The goal of the deep learning models is to estimate the missing adhesive in the gap and produce respective depth maps. The developed deep learning models utilize the U-net architecture which is very efficient in semantic segmentation as well as depth estimation. More details about the development of these models can be found in D4.3 and D1.5.

According to the KPI stated in D2.4, the deviation of the surface after printing a corrective layer should not be more than 10% of layer thickness. Similarly, it could be implied that the absolute difference between a measured depth map and an estimated depth map should not be more than 10% of the measured depth map as well. After training the deep learning models. the estimated depth maps have achieved an absolute relative difference equals to 18%. The following figure shows a comparison between a substrate depth map measured by the inspection metrology at BESI (middle), and a depth map of the same substrate estimated by the trained models (right) when given the monochrome 2D image (left) as input.

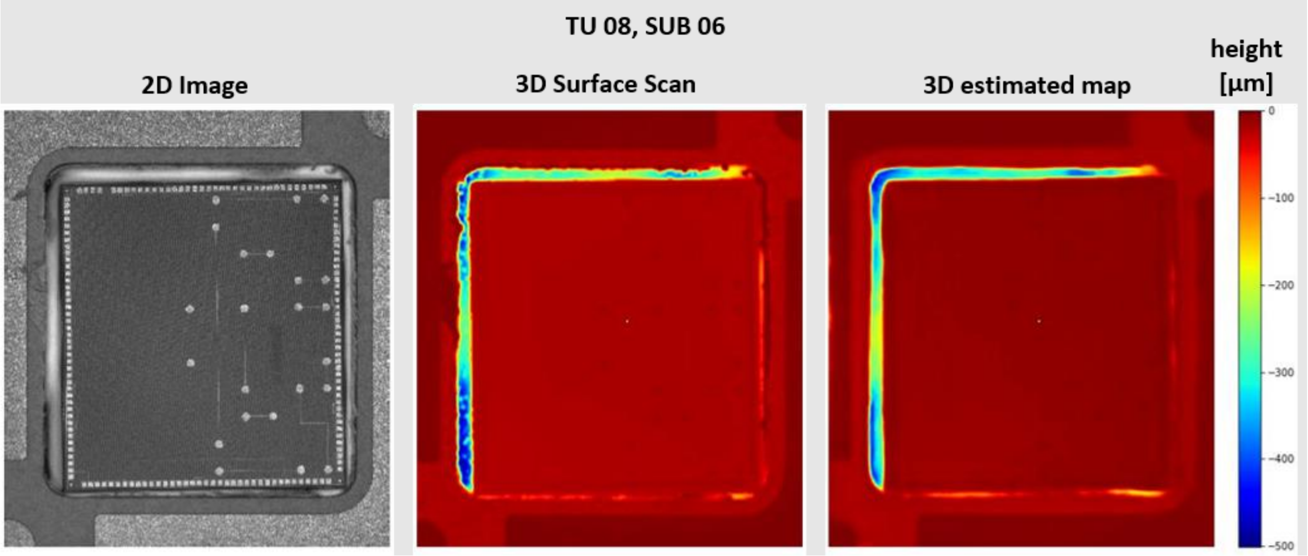


Figure 4: Comparison between an actual 3D scan and an estimated map by the trained models.

2.2.2. Gap filling feedback loop

Generating printing files

The feedback loop is initialized by generating the printing bitmaps, then sent to the inkjet printer, and finally the overprinted sample are inspected to assess the quality of the print and check whether the gap is filled properly.

For the process of generating the corrective bitmaps, the real 3D depth maps were used. That is because they are more accurate than the models' estimated depth maps. To generate the bitmaps, the resolution of all depth maps was adjusted to match the working resolution of the inkjet printer. That resolution was 1440 dpi in the x-direction and 1451.43 in the y-direction. Then the 3D depth maps were sliced based on the layer width which was also set according to the printer settings. Figure 5 shows the bitmap slices of the depth map in figure 2 based on a 50 µm layer width. Moreover, to make sure the printed ink hits only the gap and not the bare die, the contour of the gap was made thinner while the removed pixels were compensated so that the total volume of the missing adhesive is the same at the end. Figure 6 shows the same bitmaps of the same depth map after being made thinner. As shown in figures 5 and 6, thinning the depth map resulted in more bitmaps to preserve the total volume of the missing adhesive. Comparing the last bitmap in each figure shows the effect of thinning the gap contour.

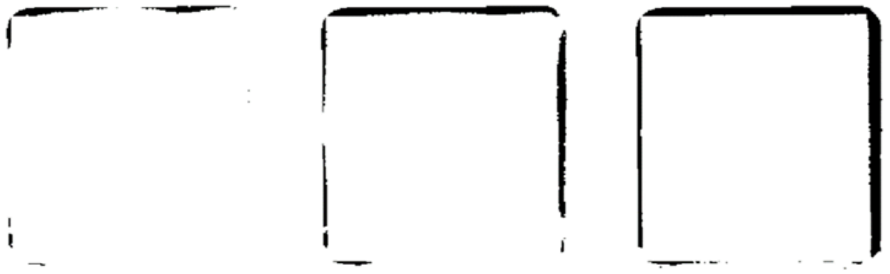


Figure 5: The bitmaps resulted from slicing the 3D depth map.

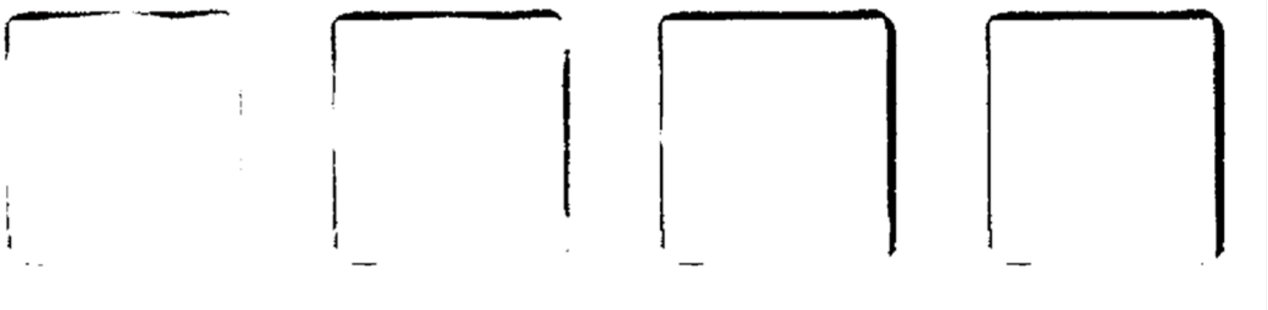


Figure 6: The bitmaps resulted from slicing the thinner 3D depth map.

Along with the bitmap layers, the locations of the fiducial points of each substrate are provided so that the printer can do the alignment correctly. Each substrate has two fiducial points which are the centre points of the two diagonal circles.

Post-printing inspection

All generated bitmaps are stored in the cloud server to be accessible by all partners, especially by NOTION to execute the prints. In the last workshop at NOTION (June 2023), the six substrate positions of 2 PCBs were used for gap filling, and three positions of another PCB were used for gap filling and for printing the dielectric base. For all samples, the used ink was the black Tiger ink (150/31801). During printing, it was noticed that the ink has low wetting on the adhesive in the gap, which means that at the border between adhesive (where it is already completely filling the gap) and ink, there will be height differences due to the high contact angle. This might make printing the conductive circuit more challenging. After overprinting the three PCBs, they were sent back to PRO to be inspected with a microscope which can generate a 2d colored image and a 2d greyscale image with defined maximum height value in µm. Figure 7 shows a sample from the inspection data of the substrates after gap filling. After that the PCBs were sent to BESI for more detailed inspection. The same inspection procedure was performed, and the resulted data were uploaded again to the cloud server.

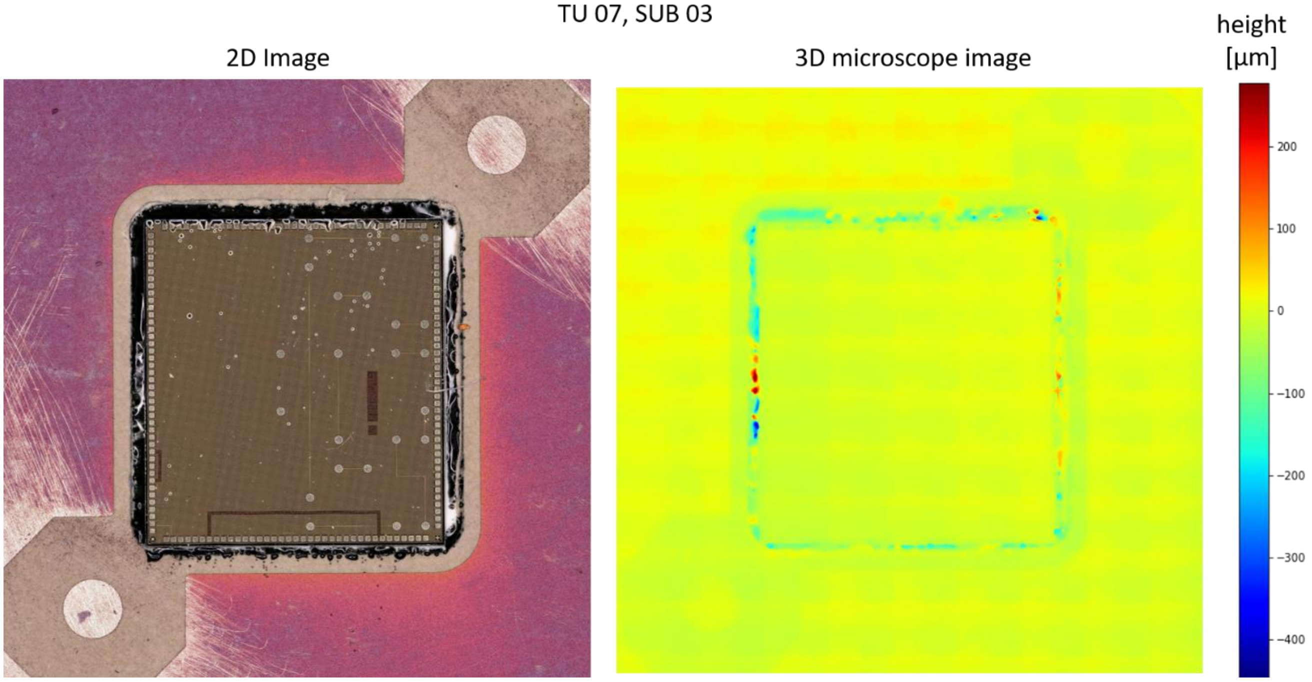


Figure 7: A sample from the inspection data of the substrates generated at PRO after gap filling.

Evaluation of the inspection data showed that the printer could hit the gap nicely and fill it correctly in most of the gap area. However, the ink hit one of the edges of the bare die (shown in figure 11 on the left), which is a problem when it comes to printing the conductive circuit. This problem most probably happens due to a mistake in the waveform causing the ink to be printed where it should not; or a mistake in the generated bitmaps. In addition, there were some locations in the gap showing excessive ink or ink shortage due to non-perfect ink spreading. In case the ink does not completely fill the gap and there is still room for more ink, another iteration of gap filling is initiated where the 3D surface scan of the overprinted sample is used for generating the printing files to fill the missing volume in the gap. However, in our case the loop is terminated since the ink excessively fills some locations of the gap and another correction step is not possible.

The following image shows a linear profile scan of a substrate after gap filling. The image was taken at NOT and shows a nicely filled gap. It also shows a shortage of ink on the left side of the scan and an excess of ink on the right; however, both have about 70 µm height difference.

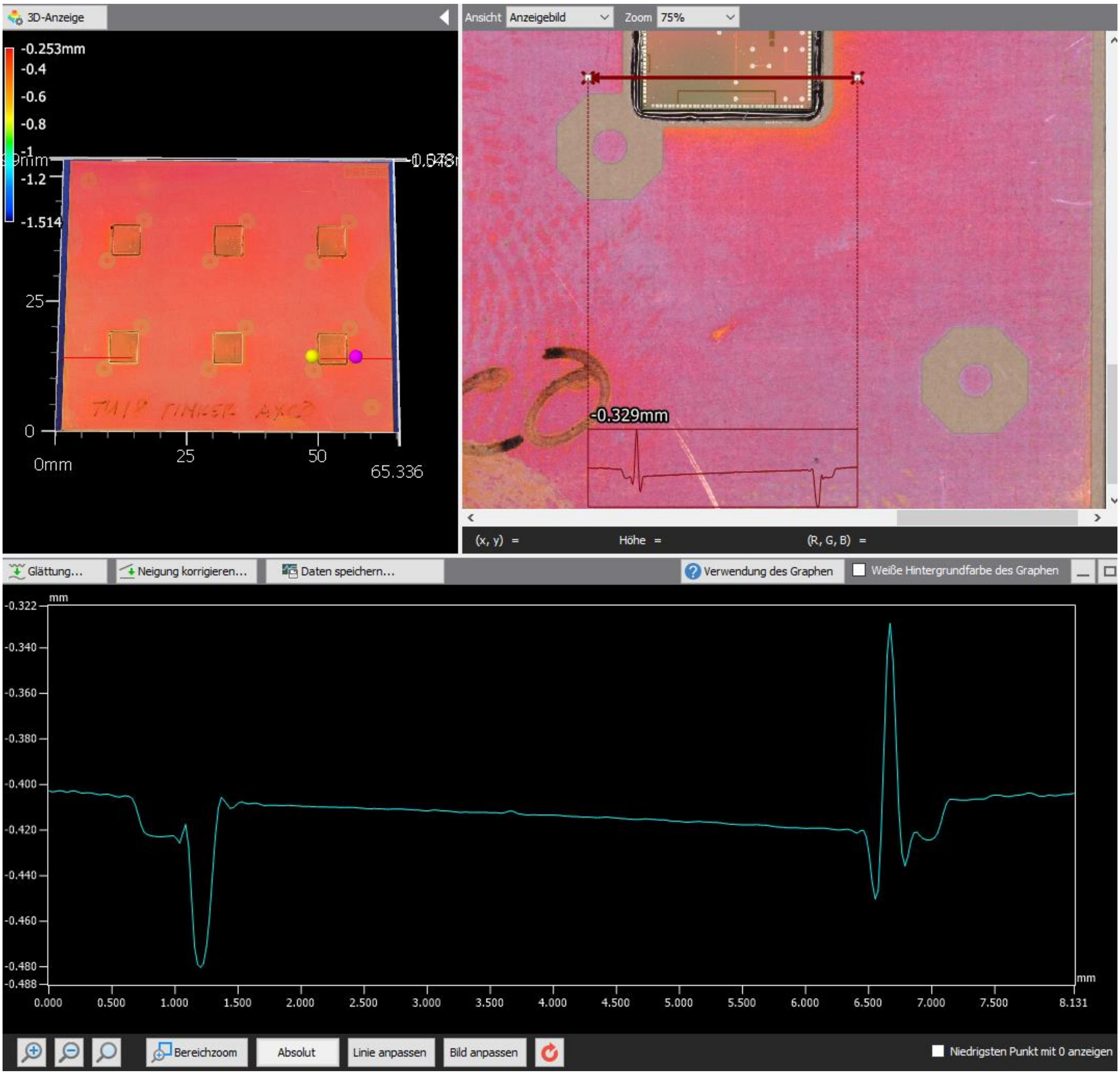
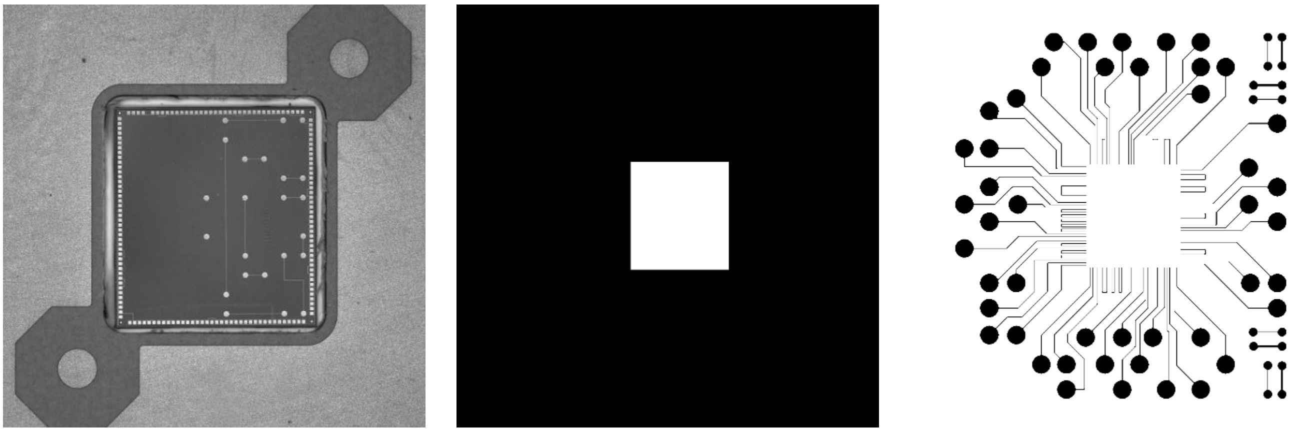


Figure 8: A line profile scan of one of the substrates used for gap filling.

2.2.3. DC layout feedback loop

Generating printing files

In this process, a conductive circuit (layout) is printed on top to contact the conductive pads of the bare die. To do this, a dielectric base is printed on top of the substrate first to eliminate any conductive points (see figure 9b). Then the conductive layout (figure 9c) is printed on top. To prove such concept, PRO joined NOT for a second workshop (March 2023) to test the spreading behaviour of the conductive ink on the dielectric material (see D5.6). The same process is repeated on a substrate with microchip and filled gaps.



9a. original substrate image 9b. dielectric base mask 9c. conductive layout

Figure 9: The DC layout printing process on top of the substrate.

The preparation of the DC layout bitmaps ran through several developments to reach the current state. In the earlier attempts, each substrate image had to be aligned with the DC layout due to the different die rotations in the substrates. The goal of the alignment is to extract the locations of the four fiducial points of the bare die in pixel coordinates of the DC layout. To do this, either the DC layout is rotated to match the rotation of the bare die, or the substrate image is counter rotated to compensate for the bare die rotation. With the latter strategy we could avoid rotating the DC layout and distorting the conductive lines; however, executing several prints would be more time consuming. With either strategy, the same number of DC layout bitmaps as the number of substrates had to be generated to execute all prints. Figure 10 shows how the substrate image is aligned to the DC layout.

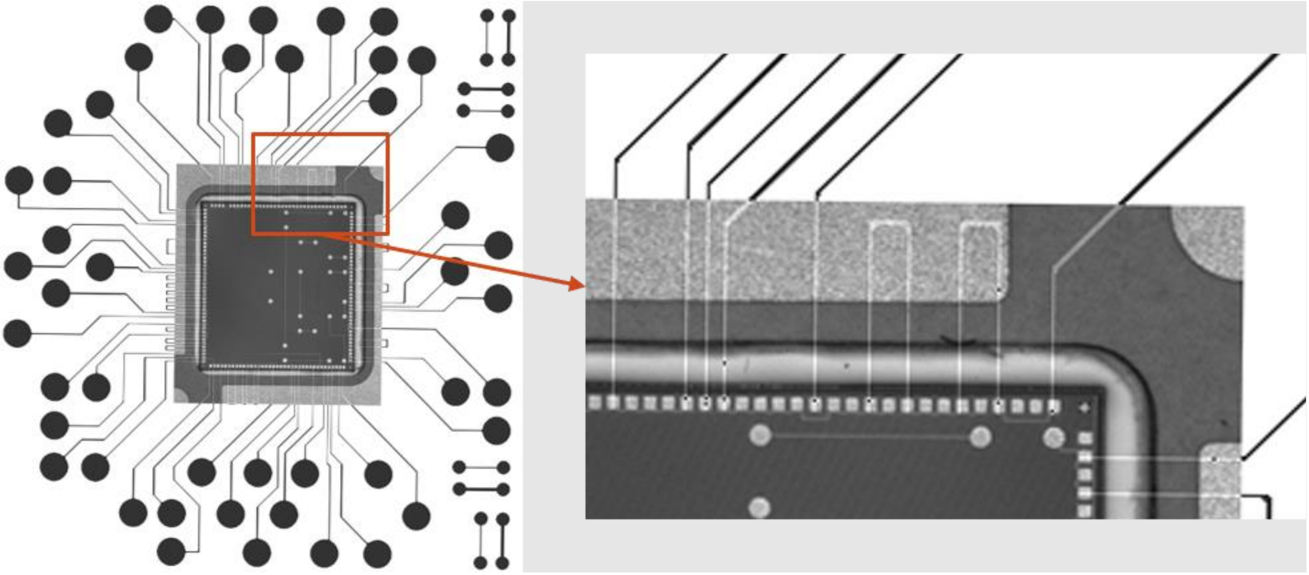


Figure 10: The alignment of the substrate image to the DC layout bitmap so that the printed silver lines accurately hit the chip conductive pads.

In the end, the inkjet printer was able to compensate for the die rotation automatically when given the locations of the fiducial points of the die in the unrotated position. Therefore, there was no need to do any prior image alignments, and additionally one DC layout bitmap with the known fiducial locations were enough to execute the prints on all substrates. Similar to gap filling bitmaps, the resolution of the DC layout bitmap was adjusted to 1440dpi.

Post-printing inspection

Evaluating the printed dielectric base showed the ink covers the conductive pads of two edges of the bare die (shown in figure 11 on the right). This maybe happens due to one or more of the following: misalignment due to a problem in detecting the fiducial points; a mistake in the dimensions of the bitmap layers, and a mistake in the locations of the fiducial points.

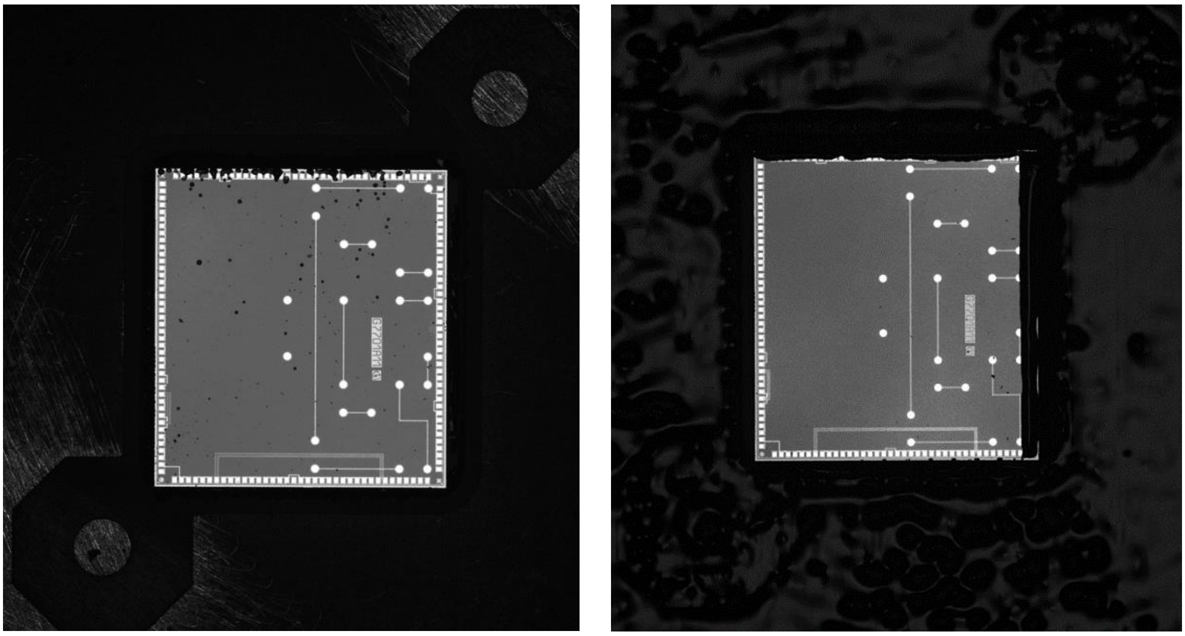
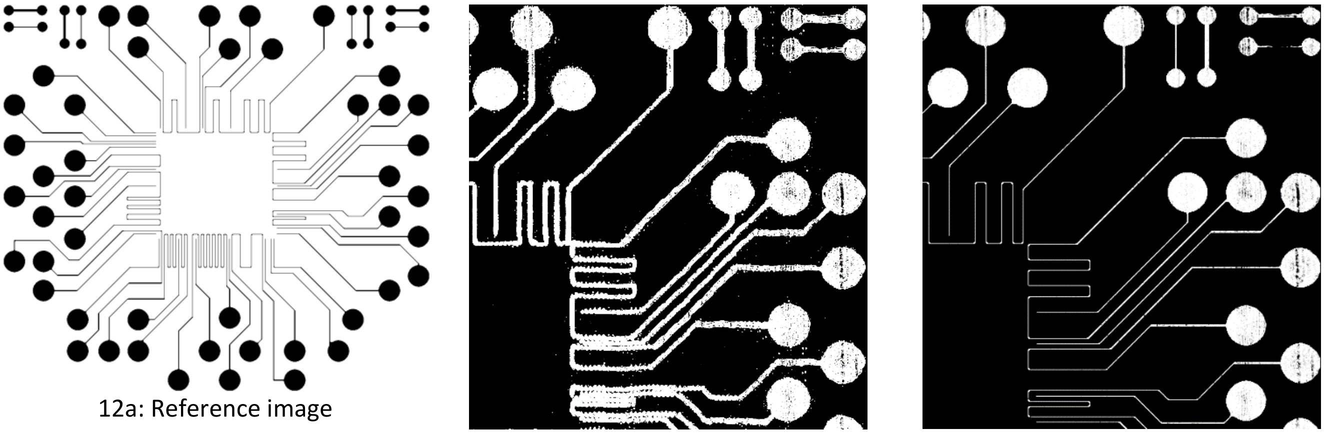


Figure 11: Quality inspection of the bare die by the BESI metrology using direct light showing some printing problems.

Since the dielectric ink already covers some of the conductive pads of the bare die, printing the conductive layout was not initialized. In the case of successful dielectric base printing, the conductive layout is printed on top. Assessing the quality of the printed layout could be done using image processing techniques which can potentially detect small cracks in the printed lines. Figure 12 shows a proof-of-concept methodology of cracks detection, segmentation and correction. The image on the left represents the printing reference image, and the one in the middle represents the right corner part of the actual printed microscope image, and finally the one on the right shows the microscope image after removing noise pixels where the black areas within the white lines represent the detected cracks. The addition of the left image and the right image would yield the correction image where it is white everywhere except for line cracks areas. After both gap filling and DC layout feedback loops are terminated, the PCBs are shipped to BOS for another conductivity inspection.



12a: Reference image

12b: Microscope image

12c: enhanced microscope image

Figure 12: Quality assessment of the printed conductive lines using image processing. (a) the reference print image. (b) the microscope image of the real printed bitmap. (c) the enhanced image with shown cracks in the conductive lines.

2.2.4. Laser Sintering Process

The Laser Sintering Process is especially needed for the post processing of printed copper tracks. In comparison printed silver tracks can also be sintered via the IR Lamp integrated in the NOTION Printer, which is not possible for printed copper due to the oxidation of the material. The parameter of the laser sintering process for the UV-curable copper Ink (IC45TM-61) are currently developed at FORTH and the sintering parameters can be adopted to the NOTION Printer as soon as the Laser System is integrated (expected in October 2023).

2.3. Interoperability Setup

2.3.1. Overview

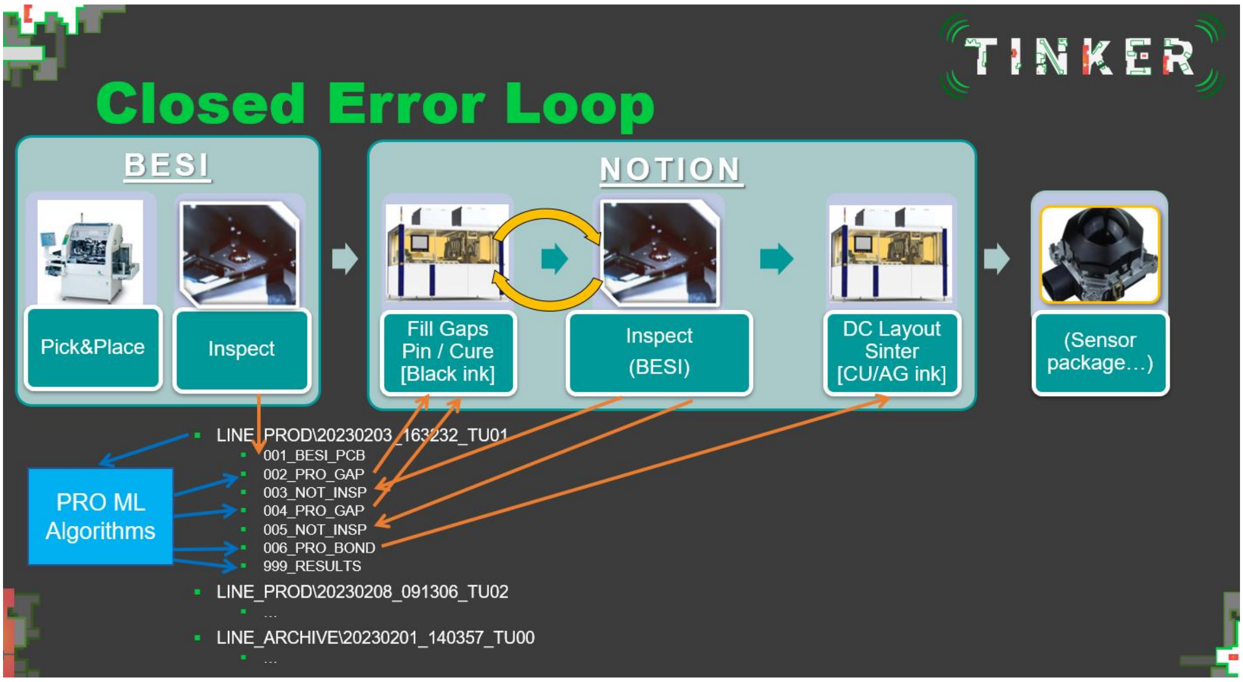
In the project, a prototype for a production line for the manufacture of radar chips is to be created. For this task, different cyber physical systems must cooperate with each other and exchange data. In other projects that PROFACTOR has worked on so far, the following solutions have been used to exchange data between systems or to coordinate workflows among each other:

- Databases - SQL/NOSQL solutions (e.g., MongoDB)
- Web services/REST Solutions
- Key-Value Store (REDIS)
- File - Folder/Cloud Data Storage
- Messaging/Stream/Event based system (ZeroMQ, AMQP, MQTT, Kafka (Hadoop), IFTTT, Node-Red, ...) resp. Agents/Queues
- Enterprise service bus
- Exchange of data via HDFS files per job
- Jupyter Notebooks (Netflix-Papermill)
- Combined Solutions

In Deliverable D6.1, a system was outlined that enables multiple agents to collaborate with each other, with JSON provided as the uniform data structure. However, an implementation of this technical infrastructure in detail (could be realized using MongoDB, for example) was not to be carried out in the project, since the current project is not focused on software, but on production processes. In the project, it was unfortunately not possible to network all the machines required for the prototype as part of the implementation of a prototypical production line. Instead, data was exchanged between the machines at the partners and the corresponding process steps were started manually and with a time delay.

Another aspect was that the project needed to have as much flexibility as possible regarding the data to be exchanged with each other, since the data format was also only gradually developed during the project. In addition, a large part of the data to be exchanged with each other is also available in binary form (images of scans, or images for printing ink for gap filling, laser sintering and DC layout).

Thus, for the exchange of data between the systems of the project partners, a common pragmatic cloud environment was chosen in which the partners/systems store their data for the respective process steps, specifically in folders. For the storage of data, all partners adhered to a certain nomenclature when creating the folders and file structures, as well as to a defined procedure for accessing these folders, so that smooth collaboration between all participants could be ensured. We will subsequently refer to this architecture as 'tinker workflow folders' (see Figure 13) and now describe it in more detail.



TINKER

Closed Error Loop

BESI

Pick&Place

Inspect

NOTION

Fill Gaps
Pin / Cure
[Black ink]

Inspect
(BESI)

DC Layout
Sinter
[CU/AG ink]

(Sensor
package…)

PRO ML
Algorithms

- LINE_PROD\20230203_163232_TU01
  - 001_BESI_PCB
  - 002_PRO_GAP
  - 003_NOT_INSP
  - 004_PRO_GAP
  - 005_NOT_INSP
  - 006_PRO_BOND
  - 999_RESULTS
- LINE_PROD\20230208_091306_TU02
  - …
- LINE_ARCHIVE\20230201_140357_TU00
  - …

Figure 13: Tinker Workflow Folders – Overview

Within the Project we use a common Cloud Space from PROFACTOR (based on “Pydio Cells” (LINK)) to share all workflow Process data between the systems/partners (BESI, PRO, NOT). URL: https://files.profactor.at/public/1193fadd008a

At the top of the directory hierarchy for the RADAR prototyping line, there are two main ‘LINE’ folders, and may also be some additional directories e.g.:

- **LINE_PROD** … contains subfolders for all running lots (concrete PCBs).
- **LINE_ARCHIVE** … data of lots will be archived into this folder if the corresponding workflows for these lots are finished.
- _DOCU … this folder shall contain meta info about any concrete system + kind of process data used.

Lot folder names contain UTC timestamps of first process event for a PCB - to be unique. Additionally, we can add ‘user friendly keys’ -> e.g., TU01, to increase the readability -> e.g., 20230203_163232_TU01. Any system on the line waits for its task, does its job and then writes result data which can be used then for following works steps. Any result data of a system is written in a subfolder of the Lot folder. For the subfolder naming we use the following nomenclature:
<3 digits step number>_<3 characters for system that writes the data [UCASE]>_<kind of data - max 10 characters [UCASE]>

The first system uses '001' as a serial number. Any following work step increases this number by 1.

e.g., 001_BESI_PCB, 002_PRO_GAP, 003_NOT_INSP, …

The following table (see Table 1) shows an overview of all systems and data involved in the RADAR prototyping workflow:

Partner / System	**3 Character short form**	**Kind of data**	**Explanation**
BESI	BES	PCB	Notion 2D (3D) measurements for any chip on the PCB after pick + place (Are used by PRO to calculate the gap filling data)
PROFACTOR	PRO	GAP	PROFACTOR files to be used by the NOTION printer for gap filling
		BOND	PROFACTOR files to be used by the NOTION printer for bonding + laser sintering.

NOTION	NOT	INSP	Notion printer - 3D measurements for any chip on the PCB AFTER gap filling. (Was realized by using BESI_PCB format again in the test environment - lacking a 3D measurement in NOT)

Table 1: Systems + Kind of Data

2.3.2. A typical workflow for the RADAR production line

1. The first system in the line (BESI) creates the initial subfolder for the PCB. And it generates a first subfolder containing the PCB/chip 3D measurement information (001_BESI_PCB).
2. If the next station PRO sees this folder, it can use the data. By using a trained model, it then generates appropriate data for gap filling for the NOTION printer (002_PRO_GAP). (This step may be skipped if not necessary - if there are no gaps and would then be followed immediately by a bonding works step!)
3. Then the NOTION printer must be contacted by PRO to do the gap filling job. After that an inspection step should be taken again to produce 3D measurements (003_NOT_INSP). In the project here BESI inspection was reused again, because there was no ability to get a 3D measurement system after the NOT printing.
4. PRO then again tries to find out if a next step gap filling is (again) necessary and generates gap filling data (004_PRO_GAP). If not, PRO generates data for the conductive layout bonding (004_PRO_BOND).
5. After the last gap filling loop iteration, the conductive layout bonding is initialized, and the NOTION printer must be contacted by PRO.
6. Finally - after Bonding has been finished by the NOT printer - an empty folder to finish working with this PCB (999_RESULTS) must be created and finally the complete PCB's folder should be moved to LINE_ARRCHIV.

Next, PRO sorts all remaining folders in ascending order within LINE_PROD and takes the 'next one' to proceed. Meanwhile BESI may have created additional folders within LINE_PROD (BESI placement may e.g., be much faster than NOT gap filling).
As said, any next 'system' in the process workflow increments the step number and then writes its data. The last station closes the process with 999_RESULTS (or maybe e.g., 999_PRO_RESULTS). All systems must process the data in ascending timestamp order. Usually, PRO will be the master.

To reiterate, a sample workflow inside the cloud server could look like the following:

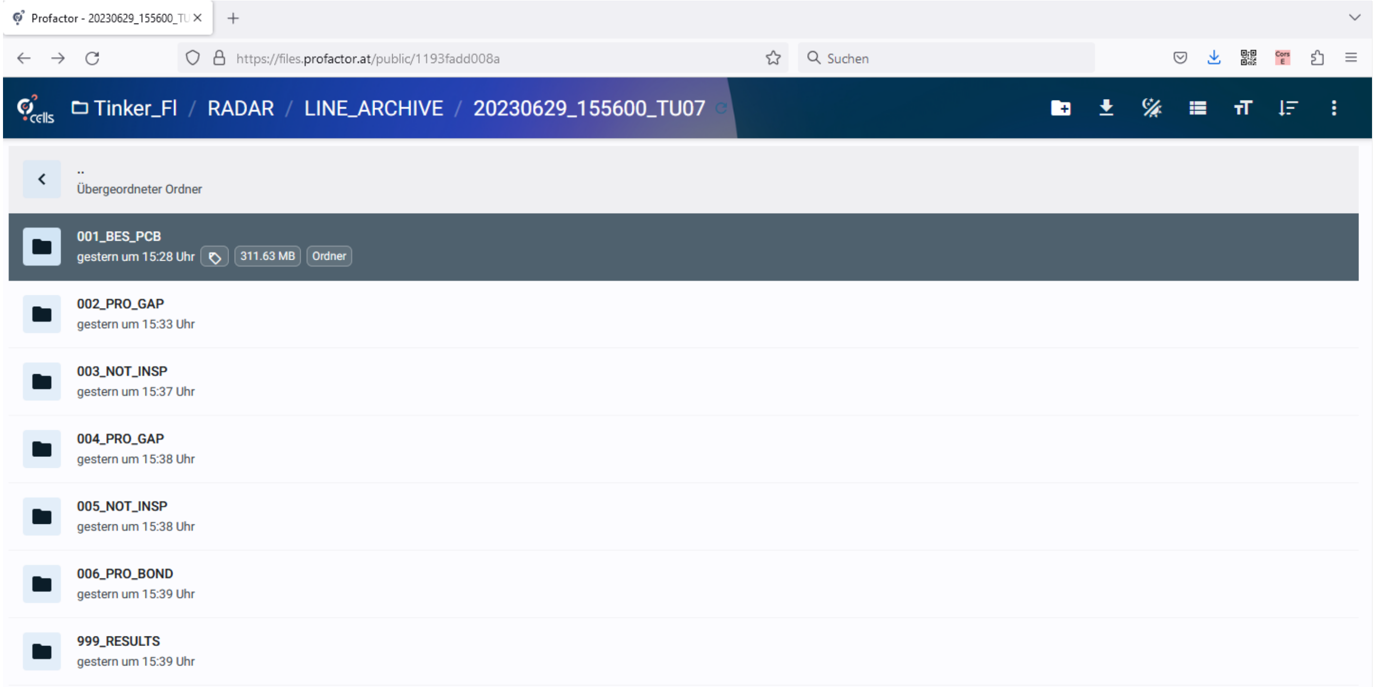
- LINE_PROD\20230314_163501_TU01\001_BESI_PCB
  ... BESI has written Results of PCB Measurements.
- LINE_PROD\20230314_163501_TU01\002_PRO_GAP
  ... PRO Model has generated files for the NOT printer for gap-filling.
- LINE_PROD\20230314_163501_TU01\003_NOT_INSP
  ... NOT has printed things + did some inspection afterwards (or BESI measurements were used again).
- LINE_PROD\20230314_163501_TU01\004_PRO_GAP
  ... PRO looked at the files before + decided another gap filling loop is necessary. + generated again files for gap filling - 2nd Loop.
- LINE_PROD\20230314_163501_TU01\005_NOT_INSP
  ... NOT has printed things again + did some inspection afterwards (or BESI measurements were used again).
- LINE_PROD\20230314_163501_TU01\006_PRO_BOND
  ... PRO looked at the files before - no more gap-filling is necessary. Now the files for bonding have been generated.
- LINE_PROD\20230314_163501_TU01\999_RESULTS
  ... maybe some results exist (some chips defect, everything was ok).
- LINE_PROD\20230314_163604_TU02
- LINE_PROD\20230314_163707_TU03

After 'LINE_PROD\20230314_163501_TU01': after '999_RESULTS' was written, all things will be moved to Archive now.

- LINE_ARCHIVE\20230314_163501_TU01
  ... Now all data from LINE_PROD has been transferred into the Archive.

2.3.3. Data transfer overview

Figure 14 shows an overview of the cloud solution for the concrete lot TU07. Figure 15 depicts the 2D image data that is generated after BESI pick and placement has happened. This data is then used by PROFACTOR to generate the corrective data needed for gap filling to be executed by the NOTION printer (Figure 16 shows the images for all corrective layers to be printed). After the last workshop, NOT sent samples of the xml job files to PRO so that PRO can generate them directly and send them to NOT along with the printing data in future printing experiments. To fulfil this, PRO wrote a script that generates xml job files for gap filling based on those samples. The location of the PCB in the coordinates of the printer is fixed and so are the locations of the six substrates, whereas the only variable parameter in those xml files is the number of bitmap layers. Figure 17 gives a small glimpse of the NOTION printer xml file needed for the gap filling work step. Sample data for the final bonding step (after gap filling was successfully done) is shown in Figure 18.


Profactor - 20230629_155600_TU
https://files.profactor.at/public/1193fadd008a
Suchen

Tinker_FI / RADAR / LINE_ARCHIVE / 20230629_155600_TU07

..
Übergeordneter Ordner

001_BES_PCB
gestern um 15:28 Uhr 311.63 MB Ordner

002_PRO_GAP
gestern um 15:33 Uhr

003_NOT_INSP
gestern um 15:37 Uhr

004_PRO_GAP
gestern um 15:38 Uhr

005_NOT_INSP
gestern um 15:38 Uhr

006_PRO_BOND
gestern um 15:39 Uhr

999_RESULTS
gestern um 15:39 Uhr

Figure 14: Sample View of all folders for Lot TU07 in the archive

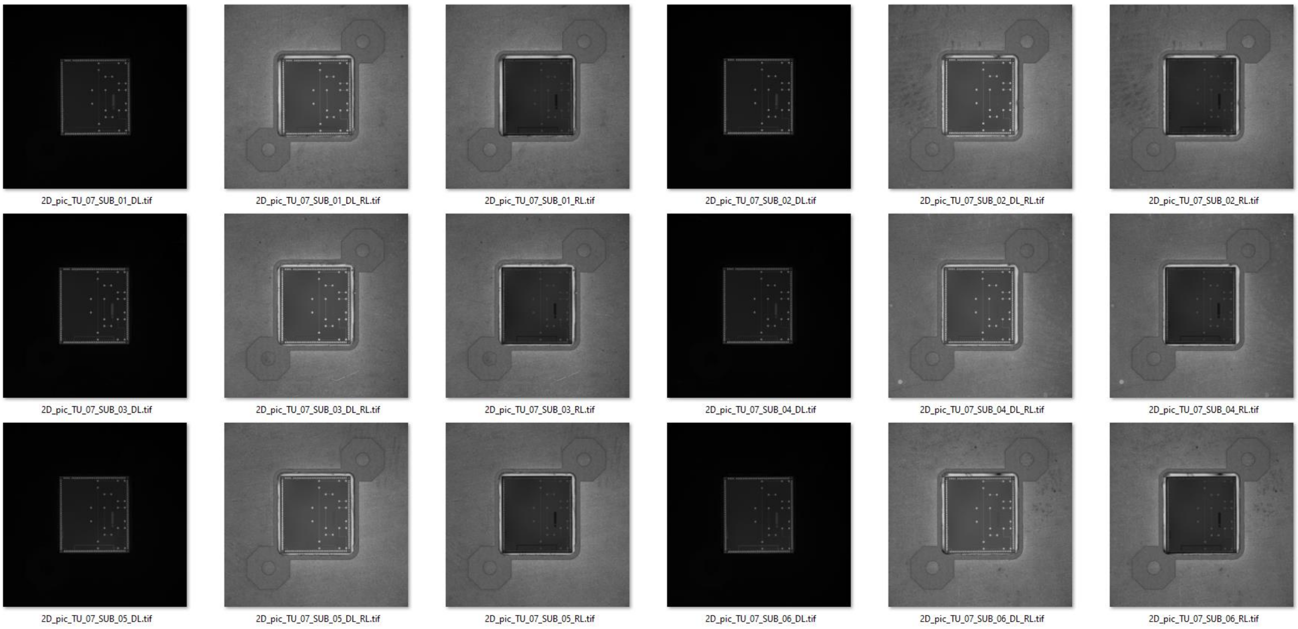

2D_pic_TU_07_SUB_01_DL.tif
2D_pic_TU_07_SUB_01_DL_RL.tif
2D_pic_TU_07_SUB_01_RL.tif
2D_pic_TU_07_SUB_02_DL.tif
2D_pic_TU_07_SUB_02_DL_RL.tif
2D_pic_TU_07_SUB_02_RL.tif
2D_pic_TU_07_SUB_03_DL.tif
2D_pic_TU_07_SUB_03_DL_RL.tif
2D_pic_TU_07_SUB_03_RL.tif
2D_pic_TU_07_SUB_04_DL.tif
2D_pic_TU_07_SUB_04_DL_RL.tif
2D_pic_TU_07_SUB_04_RL.tif
2D_pic_TU_07_SUB_05_DL.tif
2D_pic_TU_07_SUB_05_DL_RL.tif
2D_pic_TU_07_SUB_05_RL.tif
2D_pic_TU_07_SUB_06_DL.tif
2D_pic_TU_07_SUB_06_DL_RL.tif
2D_pic_TU_07_SUB_06_RL.tif

Figure 15: Sample Data of 2D-scans for TU07 from BESI to calculate images for gap filling (001_BES_PCB\2D_pics)

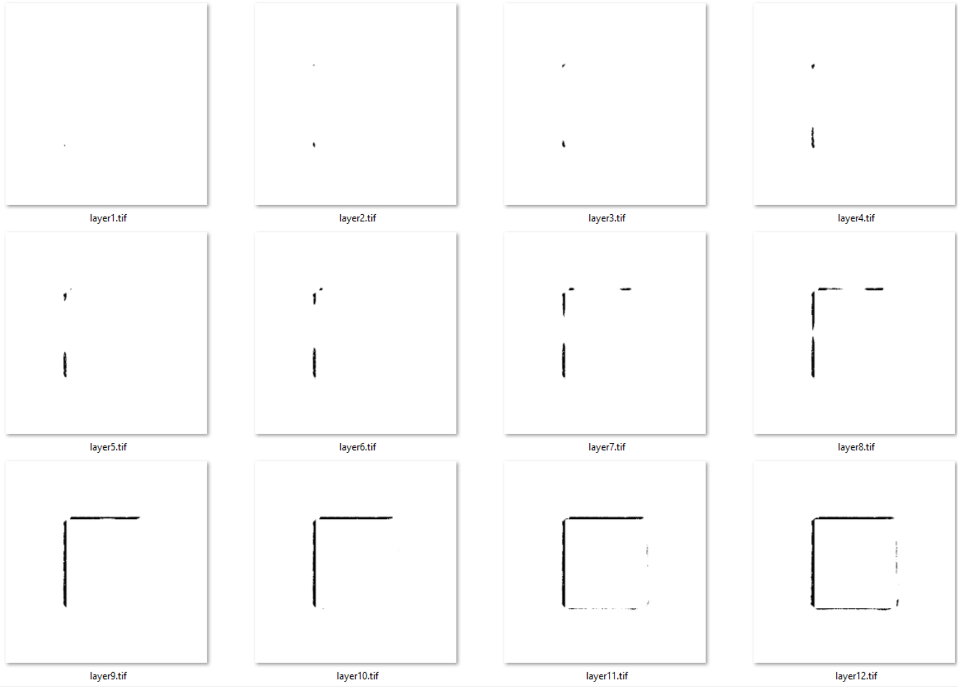
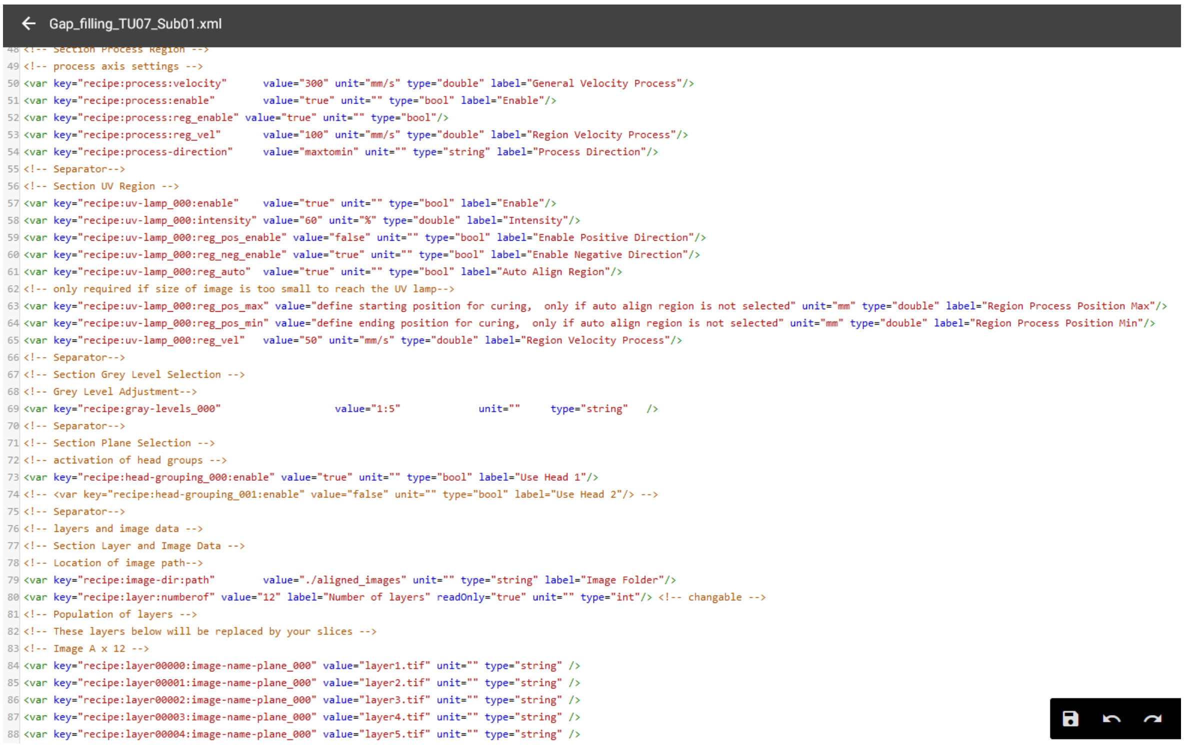


Figure 16: Sample image Data for TU07 Sub 01 from PRO for NOT-printer gap filling (002_PRO_GAP\SUB_01\aligned images)



```
<!-- Section Process Region -->
<!-- process axis settings -->
<var key="recipe:process:velocity"      value="300" unit="mm/s" type="double" label="General Velocity Process"/>
<var key="recipe:process:enable"        value="true" unit="" type="bool" label="Enable"/>
<var key="recipe:process:reg_enable" value="true" unit="" type="bool"/>
<var key="recipe:process:reg_vel"       value="100" unit="mm/s" type="double" label="Region Velocity Process"/>
<var key="recipe:process-direction"     value="maxtomin" unit="" type="string" label="Process Direction"/>
<!-- Separator-->
<!-- Section UV Region -->
<var key="recipe:uv-lamp_000:enable"    value="true" unit="" type="bool" label="Enable"/>
<var key="recipe:uv-lamp_000:intensity" value="60" unit="%" type="double" label="Intensity"/>
<var key="recipe:uv-lamp_000:reg_pos_enable" value="false" unit="" type="bool" label="Enable Positive Direction"/>
<var key="recipe:uv-lamp_000:reg_neg_enable" value="true" unit="" type="bool" label="Enable Negative Direction"/>
<var key="recipe:uv-lamp_000:reg_auto"  value="true" unit="" type="bool" label="Auto Align Region"/>
<!-- only required if size of image is too small to reach the UV lamp-->
<var key="recipe:uv-lamp_000:reg_pos_max" value="define starting position for curing,  only if auto align region is not selected" unit="mm" type="double" label="Region Process Position Max"/>
<var key="recipe:uv-lamp_000:reg_pos_min" value="define ending position for curing,  only if auto align region is not selected" unit="mm" type="double" label="Region Process Position Min"/>
<var key="recipe:uv-lamp_000:reg_vel"   value="50" unit="mm/s" type="double" label="Region Velocity Process"/>
<!-- Separator-->
<!-- Section Grey Level Selection -->
<!-- Grey Level Adjustment-->
<var key="recipe:gray-levels_000"                   value="1:5"            unit=""     type="string"   />
<!-- Separator-->
<!-- Section Plane Selection -->
<!-- activation of head groups -->
<var key="recipe:head-grouping_000:enable" value="true" unit="" type="bool" label="Use Head 1"/>
<!-- <var key="recipe:head-grouping_001:enable" value="false" unit="" type="bool" label="Use Head 2"/> -->
<!-- Separator-->
<!-- layers and image data -->
<!-- Section Layer and Image Data -->
<!-- Location of image path-->
<var key="recipe:image-dir:path"        value="./aligned_images" unit="" type="string" label="Image Folder"/>
<var key="recipe:layer:numberof" value="12" label="Number of layers" readOnly="true" unit="" type="int"/> <!-- changable -->
<!-- Population of layers -->
<!-- These layers below will be replaced by your slices -->
<!-- Image A x 12 -->
<var key="recipe:layer00000:image-name-plane_000" value="layer1.tif" unit="" type="string" />
<var key="recipe:layer00001:image-name-plane_000" value="layer2.tif" unit="" type="string" />
<var key="recipe:layer00002:image-name-plane_000" value="layer3.tif" unit="" type="string" />
<var key="recipe:layer00003:image-name-plane_000" value="layer4.tif" unit="" type="string" />
<var key="recipe:layer00004:image-name-plane_000" value="layer5.tif" unit="" type="string" />
```

Figure 17: Sample NOTION printer file for TU07 Sub 01 from PRO for NOT-printer gap filling (002_PRO_GAP\SUB_01\Gap_filling_TU07_Sub01.xml)

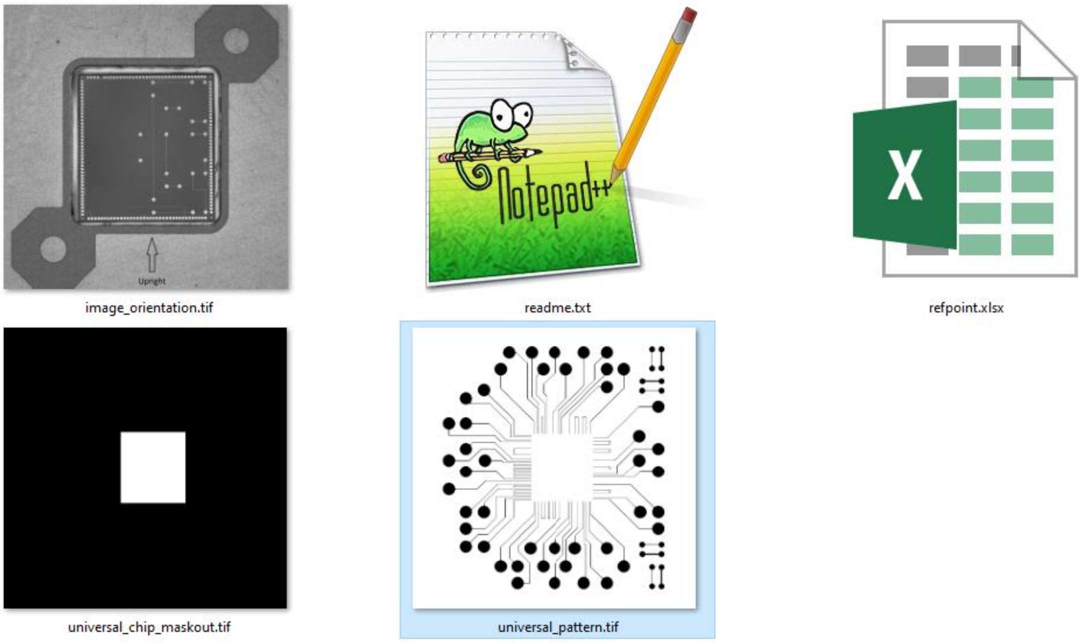


Figure 18: Sample Files needed for the final Bonding (DC/Layout) work step (006_PRO_BOND)

3. Conclusions

This deliverable outlines the configuration of the TINKER platform, incorporating closed-loop error compensation, and presents the outcomes following the implementation of this configuration.

The deliverable covers the description of closed-loop error compensation, the main interoperability structure for inkjet processes within the RADAR Tinker platform, along with details of the prototype and the workflow of the pilot line.

Machine learning models undergo progressive training using data derived from the pick and place machine. For the gap-filling procedure, bitmaps are generated along with the coordinates of two substrate fiducial points in pixel format to ensure accurate alignment with the NOTION printer. In the case of conductive circuit (DC layout) printing, bitmaps are created along with the positions of the four-chip fiducial points

Following inkjet printing at NOTION, the overprinted PCBs are forwarded to BESI for 3D inspection using their optimized 3D metrology. This marks the completion of the error compensation loop, triggering the initiation of an additional compensation step if required, based on the inspection results. The examination outcomes reveal issues related to alignment discrepancies and manufacturing residues. Notably, the DC layout printing experiments encountered greater challenges; for instance, printing the dielectric base of the conductive circuit unveiled an issue where the ink had already contacted the exposed edges of the bare die.

PRO established a cloud server for data exchange among all collaborators involved in the TINKER pilot line. All generated data is uploaded to the cloud server, adhering to a standard naming convention to enhance clarity and facilitate a seamless workflow.

4. Outlook

Improvements to the printing quality of the inkjet printer is ongoing to resolve the problems of the previous printing workshop such as the alignment and waveform issues.

A new batch of 20 bonded PCBs are being prepared by BESI that should take into consideration some parameters:

- Dispensed adhesive level should be lower than the bare die level so that the gap filling ink is printed in the whole gap for at least one layer to avoid ink and adhesive wetting problem.
- For 10 out of the 20 PCBs, the chip will be placed with raised level by about 50 µm above the PCB level.

Process development of the Laser sintering is ongoing at FRT before the integration of laser sintering at the NOTION printer which is expected in October 2023.

5. Degree of Progress

This deliverable marks the completion of the T6.4 in which the technology blocks are developed:

- Assembly of bare dies into PCBs by means of pick and place techniques.
- Allowing inline error compensation by means of an inline inspection, feedback loop and seamless data transfer using interoperability techniques.
- Process demonstration of the TINKER platform using inkjet printing technology.

6. Deviation and mitigation strategies

- Laser sintering can be integrated in the pilot line both as dislocated device or integrated part of the printer. The interoperability concept and cloud storage for data transfer enables both approaches