ECE4010J Probabilistic Methods in Engineering

Summer 2022 Term Project

Date Due: 11:59 PM, Friday, the 30$^{\text{th}}$ of July 2022

General Information

The goal of this term project is to help you apply your new-found knowledge of probability theory and statistics in extended tasks that are beyond the scope of ordinary assignments. **It is strongly recommended that you do not leave the entire project to the last minute** but rather commence work on individual parts as soon as you are able to do so.

Group Work

You will be divided into groups of *4--5 students* each.

> Each group member must be familar with and have contributed to each part of the project report. **You may not divide up the work in such a way that only certain members are invovled with certain parts.** In the event of an Honor Code violation (plagiarism or other), all members of the group will be held equally responsible for the violation. Exceptions may only be made, at my discretion, in exceptional situations.

It is therefore all group members' duty to ensure that all collaborators' contributions are plausibly their own and to check on all collaborators' work progress and verify their contributions within reason.

Project Report

The term project will be submitted **electronically only** as a typed report. Handwritten submission will not be accepted! It is recommended that you use a professional type-setting program (such as LaTeX) for your report. Unless you are able to ensure a unified font size and style for formulas and text in Microsoft Word, use of Word is *not recommended*.

Grading Policy

This term project accounts for 15% of the course grade; it will be scored based on

- **Form (3 points):** Does the report contain essential elements, such as a cover page (with title, date, list of authors), a synopsis (abstract giving the main conclusions of the project), table of contents, clear section headings, introduction, clear division into sections and appendices with informative titles and bibliography (if applicable)? Are the pages numbered? Are the text and formulas composed in a unified font? Are all figures (graphs and images) clearly labeled with identifiable source?
- **Language (3 points):** Is the style of english appropriate for a technical report? Do not treat the project as an assignment and simply number your results like part-exercises. Your text should be a single, coherent whole. The text should be a pleasant read for anyone wanting to find out about the subject matter.

  Errors in grammar and orthography (use a spell-checker!) will be penalized. Make sure that the report is interesting to read. Avoid simply repeating sentences by cut-and-paste.
- **Content (9 points):** Are the mathematical and statistical methods and deductions clearly exhibited and easy to follow? Are the conclusions well-supported by the mathematical analysis? It is important to not just copy calculations from elsewhere, but to fully make them your own, adding details and comments where necessary.

This yields the common project score. **The individual score will be adjusted according to the results of the CATME peer evaluation.** See the next section for details.

CATME Peer Evaluation

All group members are **required** to participate in the peer evaluation. Any group member who does not participate will receive zero marks for the project.

Based on the evaluation of peers, CATME determines an *Adjustment Factor (without Self)*. This common project score will be multiplied with this factor for each individual group member to determine the final score. The factor generally lies between 0 and 1.05. Based on past evaluations, the overwhelming majority of factors lies between 0.95 and 1.05, but factors of 0.4 or lower are possible in cases where students did not participate in the group work.

The systems detects attempts to manipulate the rating system by giving artificially high or low scores, collusion among two or more team members, and other anomalous scores. Where suspected instances are flagged by CATME, the instructor may override the system's Adjustment Factor.

On Plagiarism

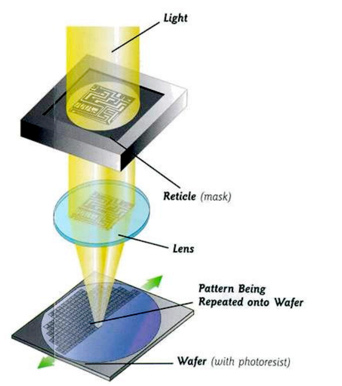
Study JI's Honor Code carefully. **Any** information from third parties (books, web sites, even conversations) that you use in your project must be accounted for in the bibliography, with a reference in the text. Follow the rules regarding the correct attribution of sources that you have learned in your English course (e.g., Vy100, Vy200). All members of a group are jointly responsible for the correct attribution of all sources in all parts of the project essay, i.e., any plagiarism will be considered a violation of the Honor Code by all group members. Every group member has a duty to confirm the origin of any part of the text.

The following list includes some specific examples of plagiarism:

- Use of any passage of three words or longer from another source without proper attribution. Use of any phrase of three words or more must be enclosed in quotation marks (``example, example, example''). This excludes set phrases (e.g., ``and so on'', ``it follows that'') and very precise technical terminology (e.g., ``without loss of generality'', ``reject the null hypothesis'') that cannot be paraphrased,
- Use of material from an uncredited source, making very minor changes (like word order or verb tense) to avoid the three-word rule.
- Inclusion of facts, data, ideas or theories originally thought of by someone else, without giving that person (organization, etc.) credit.
- Paraphrasing of ideas or theories without crediting the original thinker.
- Use of images, computer code and other tools and media without appropriate credit to their creator and in accordance with relevant copyright laws.

Instances of plagiarism. will be reported to the Honor Council. **Please ensure good communication and close collaboration with your team.**

Photolithography Overlay for Patterning of Integrated Circuitry[1]



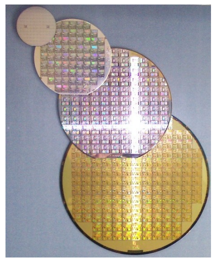
Principle of photolithography. Figure taken from https://willson.cm.utexas.edu/Research/Sub_Files/Immersion/index.php.

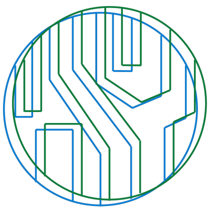
Photolithography is used to create integrated circuits (*dies*) directly from solid material. A light source creates a chip pattern on a wafer by burning away excess material. The material contributing to the pattern is protected by a mask. Modern process create three-dimensional chip networks in this way, whereby a die consists of several layers of circuits. Many dies are collected on a single *wafer*.

Due to the multi-layer imprinting of the dies, it is crucial that the different layers remain perfectly aligned during the lithography process. Nevertheless, there is always some amount of shifting and continual error correction needs to take place. Within each die there are control points whose position is measured. Their deviation from the expected position is used to calculate how the machine alignment should be modified.

In this two-dimensional setting, each control point in a die has nominal coordinates $(X + x, Y + y)$. Here, (X, Y) is the position of the die while (x, y) is the nominal coordinate within each die (i.e., relative to the die position). The *overlay error* (o_x, o_y) is the deviation from the nominal coordinates and will be different at each control point. Hence, for each control point, the actual position is given by

$$x_{\text{actual}} = X + x + o_x(X, Y, x, y), \qquad y_{\text{actual}} = Y + y + o_y(X, Y, x, y).$$


Wafers with dies. Figure taken from https://commons.wikimedia.org/wiki/File:Wafer_2_Zoll_bis_8_Zoll.jpg.


Symbolic representation of overlay error in two circuit layers. Figure provided by Prof. Djurdjanovic

It is now of interest to model the overlay errors so that by adjusting the process machinery the errors may be corrected. Overlay errors depending on the position (X, Y) of the die (*interfield errors*) are corrected by adjusting the position of the wafer, while errors depending on the position (x, y) within a die (*intrafield errors*) are corrected by adjusting the alignment of the light source.

Some actual experimental data (slightly fuzzed to protect trade secrets) for the overlay errors of a single specific wafer has been uploaded to Canvas. Fit the data to the model

$$o_x(X, Y, x, y) = \alpha_0 + \alpha_1 X + \alpha_2 Y + \alpha_3 XY + \alpha_4 X^2 + \alpha_5 Y^2 + \alpha_6 x + \alpha_7 y + \alpha_8 xy + \alpha_9 x^2 + \alpha_{10} y^2,$$
$$o_y(X, Y, x, y) = \beta_0 + \beta_1 X + \beta_2 Y + \beta_3 XY + \beta_4 X^2 + \beta_5 Y^2 + \beta_6 x + \beta_7 y + \beta_8 xy + \beta_9 x^2 + \beta_{10} y^2.$$

Find the coefficients and analyze the model (using measures such as R^2, PRESS or other means). Can the model be simplified for the given data, i.e., are all the terms necessary? Would a more extensive model (perhaps using mixed terms such as $x \cdot X$, $x \cdot Y$, etc., or cubic and higher-order terms) improve the fit? Try to find an optimal model, using either an algorithm or by testing all possible models. Since you are now modelling two variables as functions of the regressors, you may want to research how to treat them both simultaneously, i.e., as a vector-valued response variable, rather than individually.

Your report should provide a summary of this topic and discuss the statistical models. Feel free to go into as much detail on lithography as you think appropriate.

References

[1] Asad Ul Haq and Dragan Djurdjanovic. Robust control of overlay errors in photolithography processes. *IEEE Transactions on Semiconductor Manufacturing*, 32:320--333, 2019. `https://ieeexplore.ieee.org/document/8712416`.

[1] This project was suggested and the experimental data provided by Dragan Djurdjanovic, Professor at the Walker Department of Mechanical Engineering at the University of Texas at Austin. Prof. Djurdjanovic frequently teaches courses in the summer term at the Joint Institute. His work on this topic is published in the IEEE Transactions on Semiconductor Manufacturing [1].