# Application of Multiple Linear regression for Indirect Tracking of Functional Target for Respiratory Compensation in Radiotherapy

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# Approaches

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- Do nothing
- Gating
- Controlled-breath
- Probability-based planning (planning tumor volume)
- Displacing multi-leaf collimator (MLC)
- Changing configuration of MLC
- **Using patient support structure to compensate movement**

# Signals

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- 8 sets of 2D signals
- 3 surogate markers per record
- 6-10 points-of-interest
- Duration: from 300 to 500 frames (150 - 400 sec.)
- Overall 87 signal-pairs


- We thank
  - Jonas Venius and his colleagues for help in collecting signals
  - Gabrielius Čaplinskas for extracting them from DICOMs

# Motion directions

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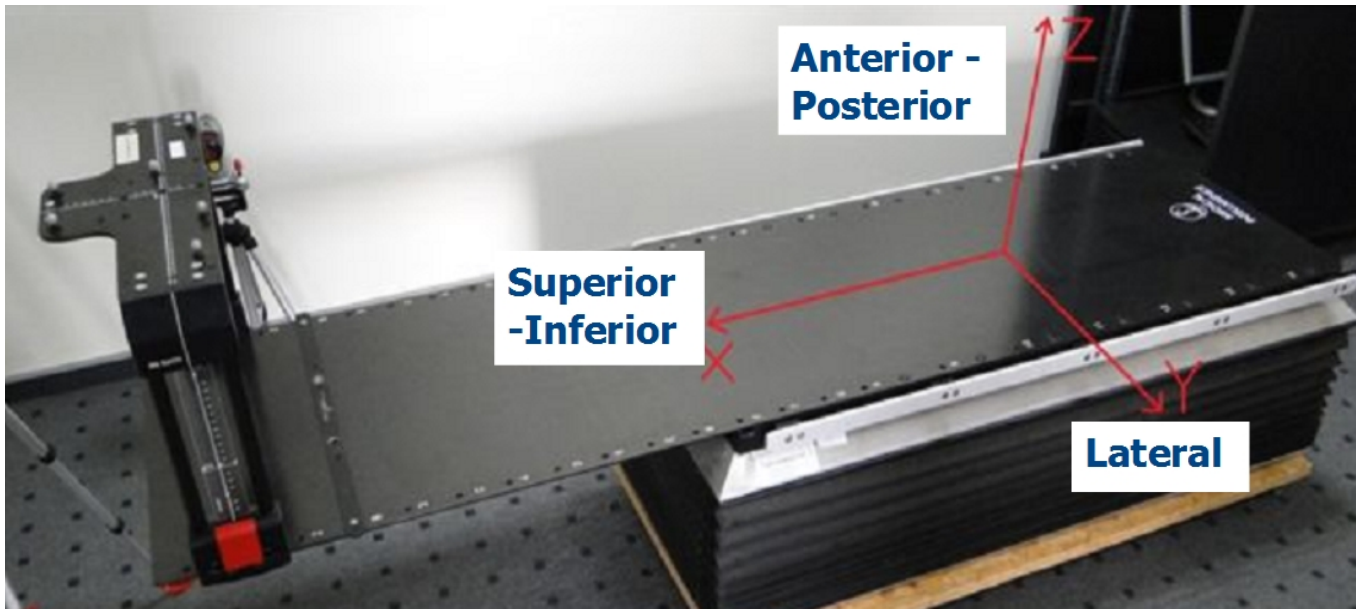
- 5 series: anterior-posterior and lateral directions.
- 3 series: anterior-posterior and superior-inferior directions.



# Algorithmic Solution

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- Signals transformation:

$$\tilde{x}_{ij} = x_{ij} - \min(x_{i1}, x_{i2}, \ldots, x_{in})$$
$$\tilde{y}_{ij} = y_{ij} - \min(y_{i1}, y_{i2}, \ldots, y_{in})$$

- Multiple linear regression:

$$y_i = \beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n$$

# Loss function

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- Mean absolute error:

$$MAE = \frac{\sum_{i=1}^{n} \sqrt{(\hat{x}_i^t - x_i^t)^2 + (\hat{y}_i^t - y_i^t)^2}}{n}.$$

- Root mean square error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (\hat{x}_i^t - x_i^t)^2 + (\hat{y}_i^t - y_i^t)^2}{n}}.$$

$t_i = (x_i^t, y_i^t)$ - true position of the tumor at time $i$
$\hat{t}_i = (\hat{x}_i^t, \hat{y}_i^t)$ - prediction at time $i$

# Results

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| Model | Simple linear regression | | | | | | Multiple linear regression | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MAE, mm | RMSE, mm | p-value | | $R^2_{adj}$ | | MAE, mm | RMSE, mm | p-value | | $R^2_{adj}$ | |
| | | | $x$ | $y$ | $x$ | $y$ | | | $x$ | $y$ | $x$ | $y$ |
| **P3~P0** | 0.28 | 0.32 | 0.4 | 0.01 | 0.81 | 0.88 | 0.15 | 0.17 | 0.49 | 0.18 | 0.86 | 0.98 |
| **P3~P1** | 0.72 | 0.79 | 0 | 0.06 | 0.69 | 0.71 | 0.22 | 0.26 | 0 | 0 | 0.7 | 0.91 |
| **P3~P2** | 0.73 | 0.8 | 0.32 | 0.05 | 0.78 | 0.52 | 0.39 | 0.47 | 0.28 | 0 | 0.79 | 0.76 |
| **P4~P0** | 0.39 | 0.43 | 0.28 | 0.02 | 0.37 | 0.57 | 0.24 | 0.27 | 0.98 | 0 | 0.58 | 0.89 |
| **P4~P1** | 0.53 | 0.57 | 0.22 | 0.02 | 0.32 | 0.52 | 0.33 | 0.37 | 0.24 | 0 | 0.33 | 0.72 |
| **P4~P2** | 0.51 | 0.55 | 0.66 | 0.02 | 0.49 | 0.63 | 0.29 | 0.34 | 0.7 | 0 | 0.49 | 0.77 |
| **P6~P0** | 0.26 | 0.31 | 0 | 0.01 | 0.94 | 0.87 | **0.13** | **0.15** | 0 | 0 | 0.94 | 0.98 |
| **P6~P1** | 0.76 | 0.84 | 0 | 0.05 | 0.91 | 0.75 | 0.21 | 0.25 | 0 | 0 | 0.91 | 0.9 |
| **P6~P2** | 0.77 | 0.86 | 0 | 0.04 | 0.77 | 0.51 | **0.41** | **0.51** | 0.01 | 0 | 0.77 | 0.74 |
| **P7~P0** | 0.26 | 0.29 | 0.75 | 0.25 | 0.7 | 0.88 | 0.17 | 0.2 | 0.96 | 0 | 0.72 | 0.95 |
| **P7~P1** | 0.67 | 0.74 | 0.81 | 0.06 | 0.66 | 0.77 | 0.24 | 0.27 | 0.77 | 0 | 0.66 | 0.85 |
| **P7~P2** | 0.68 | 0.75 | 0.96 | 0.05 | 0.47 | 0.61 | 0.4 | 0.47 | 0.93 | 0 | 0.47 | 0.7 |

# Simple vs Multiple linear regression (relation P6∼P0)

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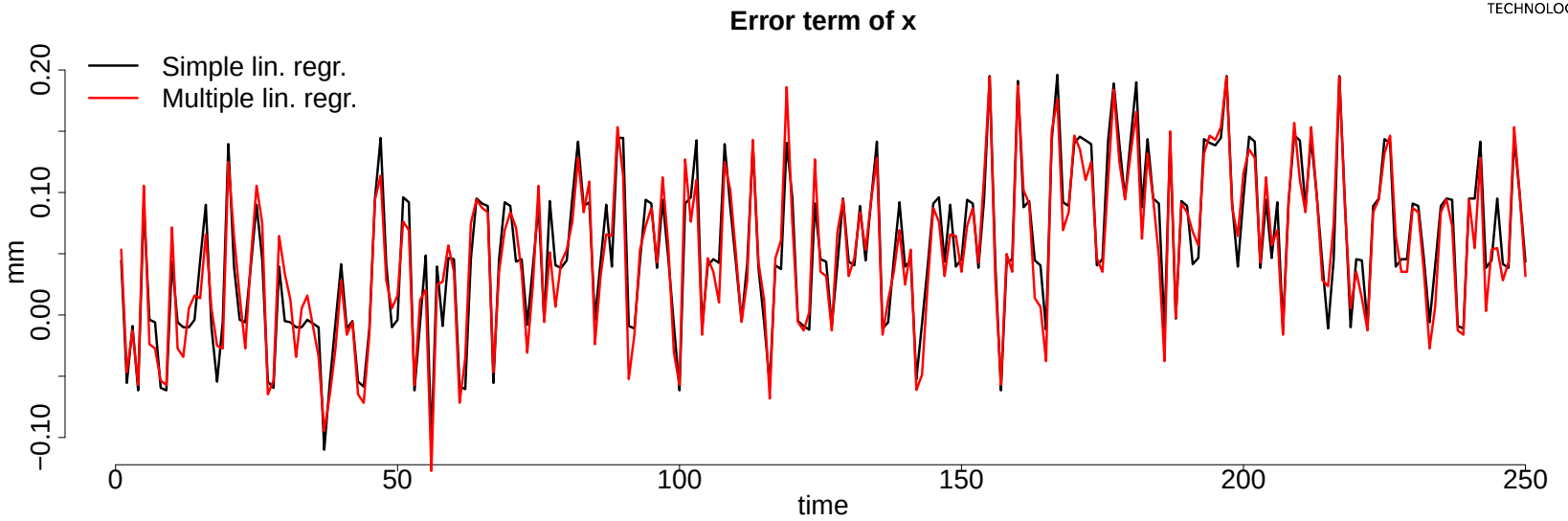


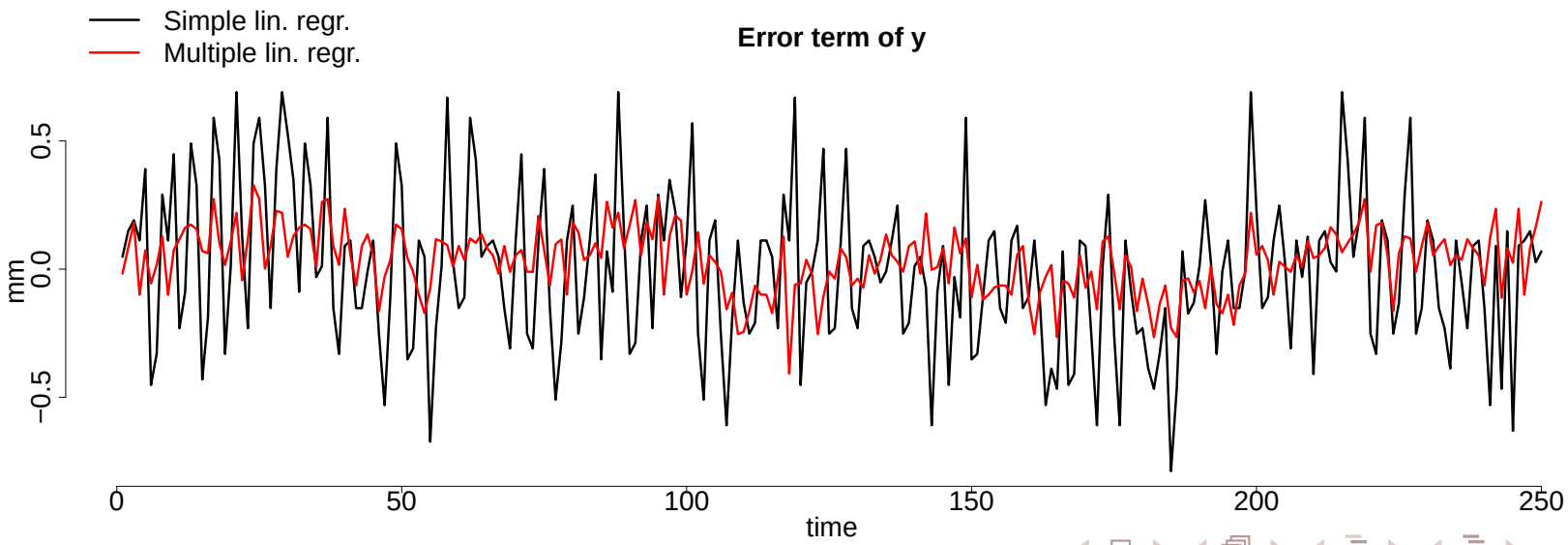

# Position of external marker (relations P6∼P0,P1,P2)

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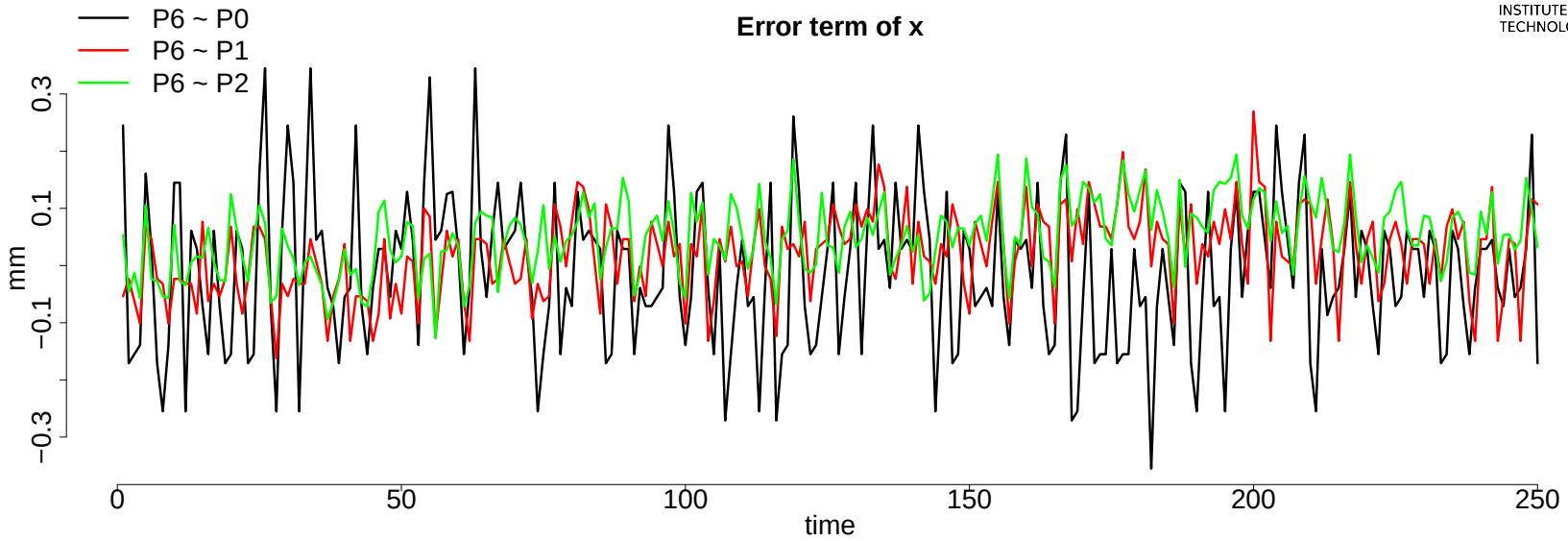


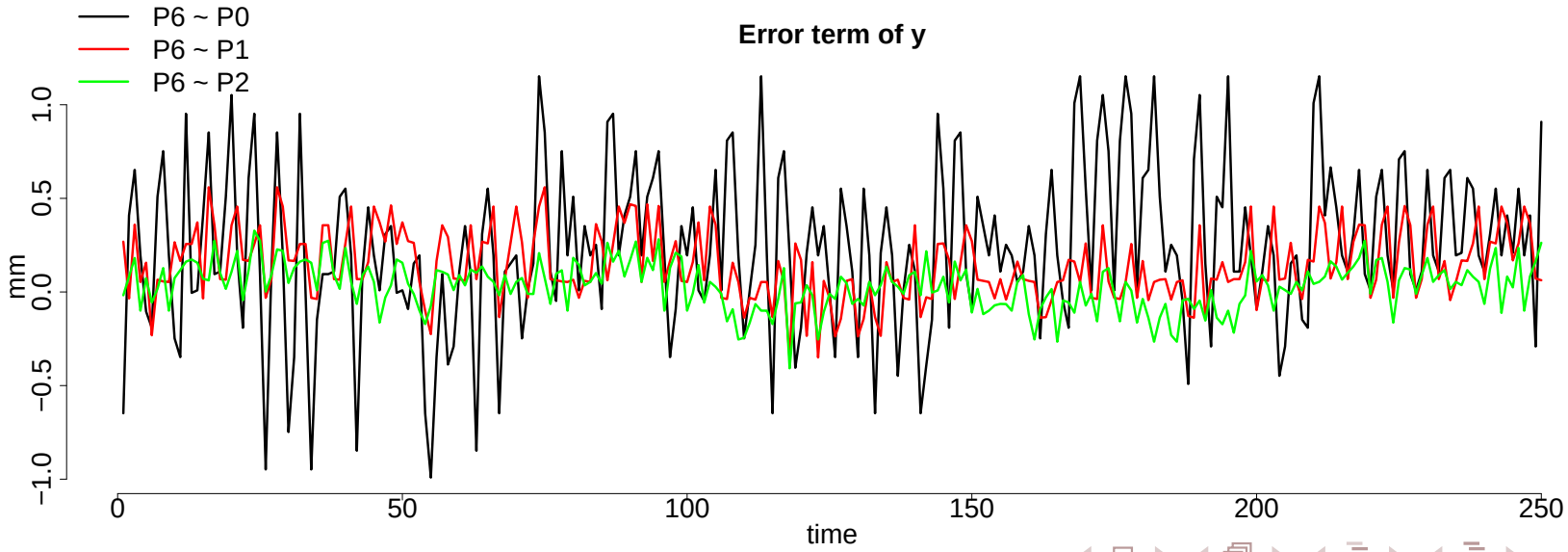

# Results (overall models)

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| | Simple linear regression | | Multiple linear regression | |
|---|---|---|---|---|
| | MAE, mm | RMSE, mm | MAE, mm | RMSE, mm |
| **Average** | 1.069 | 1.245 | 0.81 | 0.958 |
| **Min** | 0.26 | 0.29 | 0.13 | 0.15 |
| **Max** | 3.44 | 4.01 | 3.35 | 4.05 |

# Results and Conclusions

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- Multiple linear regression model:
  - increases testing accuracy
  - improves the values of $R^2_{adj}$
  - regression residuals are autocorrelated
- Better result are obtained using markers with a greater range of movement and
  - middle abdomen if lateral direction is ignored
  - otherwise upper abdomen

# Future Plans

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- Experiments with more complex regression cases
- Perform experiments
  - using only one coordinate with the largest amplitude
  - using coordinates of different external markers
- **Analyze respiratory motion prediction and design cases of an overall radiation therapy system with respiratory motion compensation**
  - We already have some results in predicting respiratory motion
  - More results in relating external markers and targets

# THANKS