Algorithms for intelligent prediction of landslide displacements

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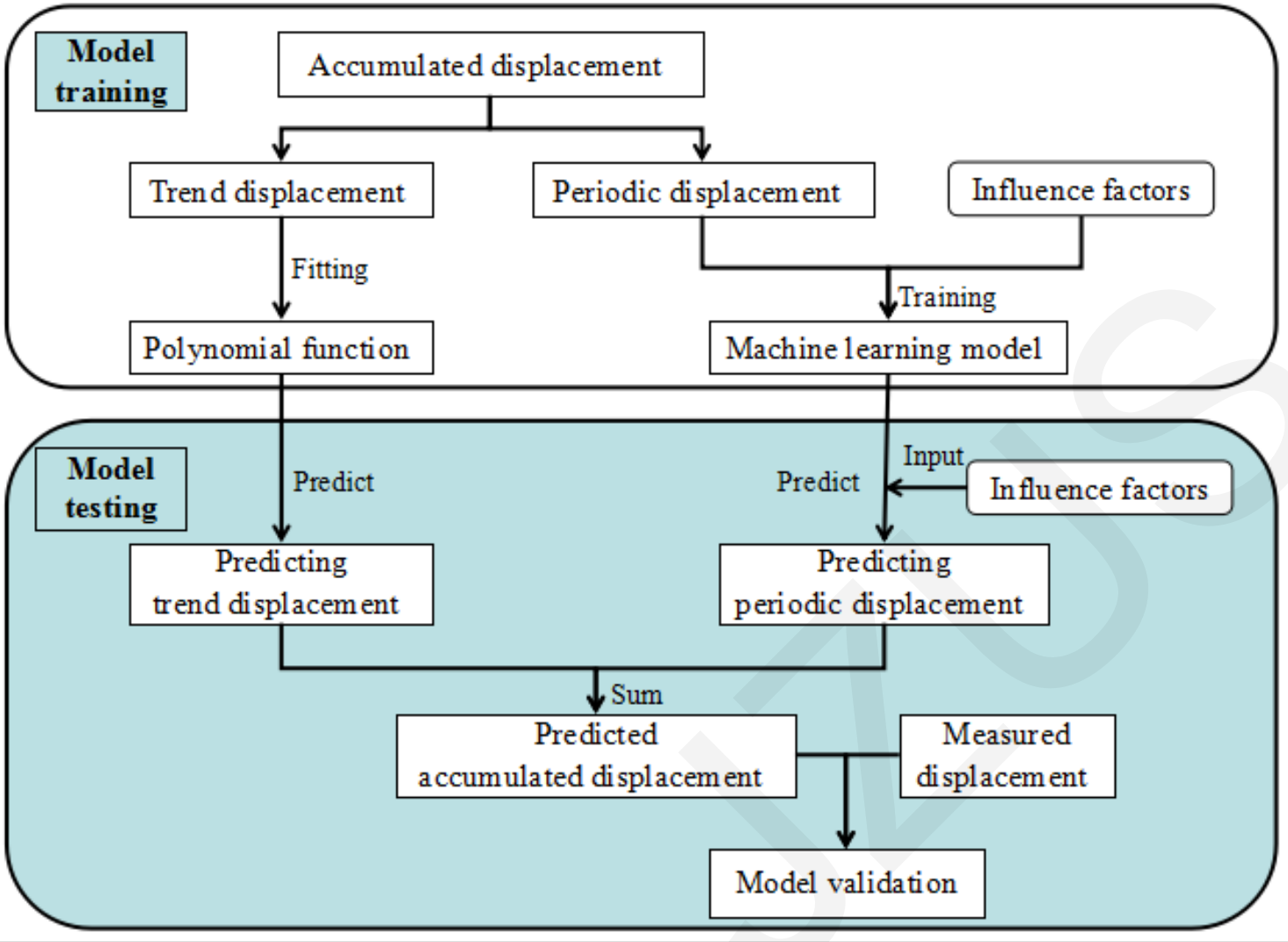
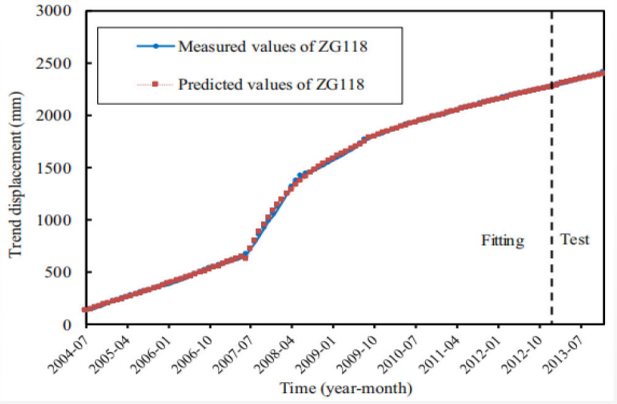


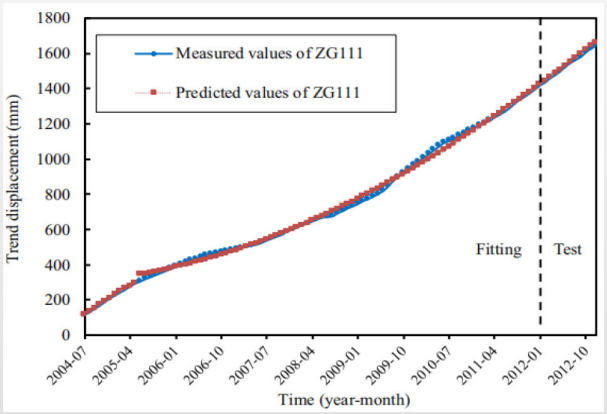
Flowchart of the prediction model

- The moving average method was applied to decompose the accumulated displacement into the trend term and periodic term.
- The trend displacement was predicted by a polynomial model.
- The periodic displacement was predicted by the machine learning models.
- The total accumulated displacement was obtained by adding the predicted trend and periodic displacements.

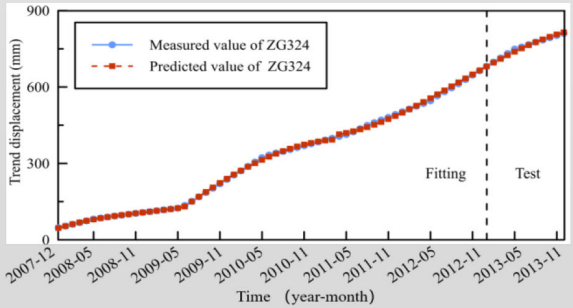
Trend displacement



Baishuihe landslide



Bazimen landslide



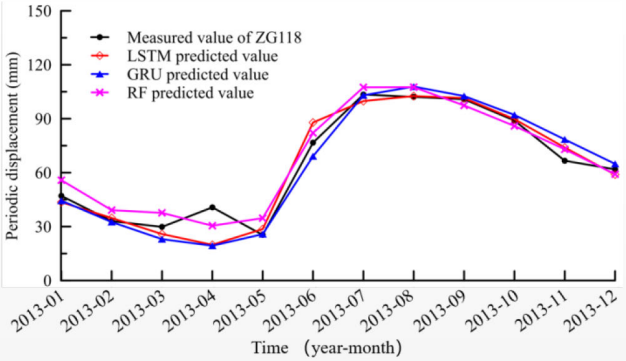
Bajiabao landslide

The trend displacement was predicted with a cubic polynomial function:

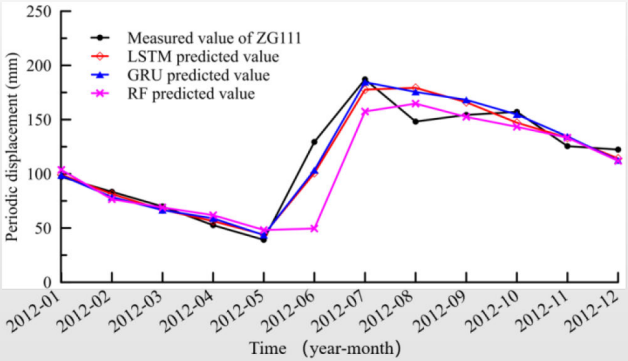
$$\phi(t) = \frac{D_t + D_{t-1} + \cdots + D_{t-n+1}}{k} (t = k, k+1, \cdots, n)$$

The predicted trend displacement calculated by the cubic polynomial function agrees well with the measured data

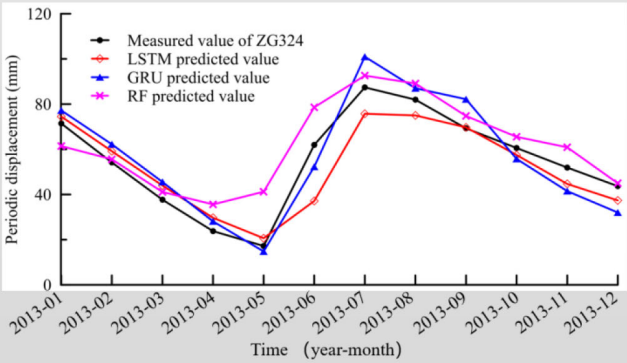
Periodic displacement



Baishuihe landslide



Bazimen landslide



Bajiabao landslide

The periodic displacement was predicted by three machine models:

- **Long Short-Term Memory (LSTM) neural networks**
- **Random Forest (RF) algorithm**
- **Gated Recurrent Unit (GRU) algorithm**

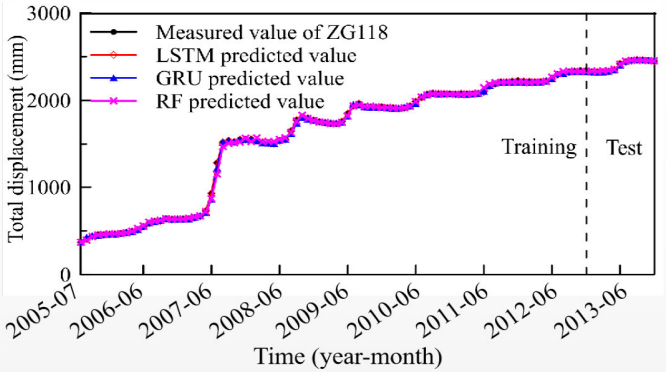
The three machine learning models we studied (LSTM, GRU and RF) were able to accurately predict periodic displacement.

Comparison of accuracy of predicted periodic displacement for three landslides

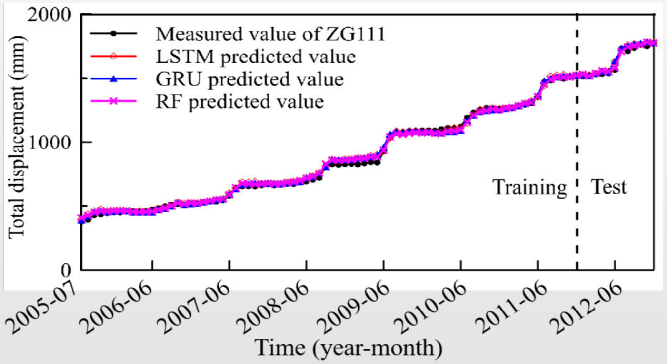
Landslide	MAPE (%)			RMSE (mm)		
	LSTM	GRU	RF	LSTM	GRU	RF
Baishuihe	10.5	10.7	13.5	7.5	8.0	6.5
Bazimen	8.6	8.4	14.2	13.8	12.6	26.0
Baijiabao	14.2	15.6	24.4	9.2	8.8	10.5

- The predictions by the LSTM and GRU models were similar and had approximately the same margin of error.
- The LSTM and GRU models predict the periodic displacement more reliably than the RF model.

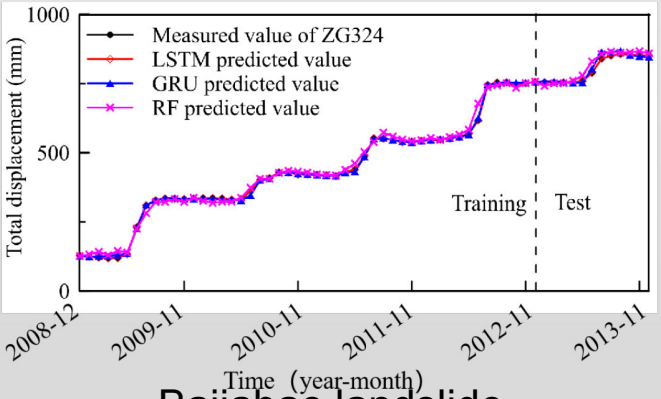
Total displacement



Baishuihe landslide



Bazimen landslide



Bajiabao landslide

- The total displacement was obtained from the sum of the predicted trend and periodic displacements.
- The proposed dynamic modelling approach, using time series analysis and machine learning models, had accurate results in predicting total displacement.

Conclusion

- The proposed dynamic modelling approach, using time series analysis and machine learning models, can accurately predict the landslide displacement.
- The LSTM and GRU algorithms were able to learn rules from earlier time steps and making use of the historical information. Therefore, the LSTM and GRU models predict the periodic displacement more reliably than the RF model.