Influenza Surveillance using Search Engine, SNS, On-line Shopping, Q&A Service and Past Flu Patients

Abstract

**Background:** Influenza, an infectious disease, causes many deaths worldwide. Predicting influenza victims during epidemics is an important task for clinical, hospital, and community outbreak preparation.

**Objective:** On-line user-generated contents (UGC), primarily in the form of social media posts or search query logs, are generally used for prediction for reaction to sudden and unusual outbreaks. However, most studies rely only on the UGC as their resource and do not use various UGCs. Our study aims to solve these questions about Influenza prediction: Which model is the best? What combination of multiple UGCs works well? What is the nature of each UGC?

**Methods:** We adapt some models, LASSO Regression, Huber Regression, Support Vector Machine regression with Linear kernel (SVR) and Random Forest, to test the influenza volume prediction in Japan during 2015 – 2018. For that, we use on-line five data resources: (1) past flu patients, (2) SNS (Twitter), (3) search engines (Yahoo! Japan), (4) shopping services (Yahoo! Shopping), and (5) Q&A services (Yahoo! Chiebukuro) as resources of each model. We then validate respective resources contributions using the best model, Huber Regression, with all resources except one resource. Finally, we use Bayesian change point method for ascertaining whether the trend of time series on any resources is reflected in the trend of flu patient count or not.

**Results:** Our experiments show Huber Regression model based on various data resources produces the most accurate results. The coefficient of determination $R^2$ are 0.907 from 2015 – 2016, 0.889 from 2016 – 2017 and 0.917 from 2017 – 2018 in predicting influenza 2 week ahead of the current date. Then, from the change point analysis, we get the result that search query logs and social media posts for three years represents these resources as a good predictor. The results of Sensitivity, is one metric, are 80% in search query and 75% in social media posts from 2017–2018.

**Conclusions:** We show that Huber Regression based on various data resources is strong for outliers and is suitable for the flu prediction. Additionally, we indicate the characteristics of each resource for the flu prediction.
Keywords: Disease outbreak; Disease surveillance; Influenza; Machine learning; User-generated content

Introduction

Background
Predicting epidemics of infections can reduce time and effort exerted by public health professionals and medical institutions, resulting in more efficient service. Influenza, especially infections commonly known as the flu, can infect people of any age: even today, it causes 290,000–650,000 deaths annually [1]. In Japan, predicting the dynamics of seasonal flu outbreaks is important. Two well-known aspects of flu outbreaks in temperate areas such as Japan are that (i) flu outbreaks happen every year during December–March and (ii) the flu has a seasonal cycle. Considering these features, one study has predicted outbreaks using only the number of flu patients in the past [2]. However, this research exhibits some limitation especially in term of the method that is used, it can not handle unexpected epidemics that differ from those of a usual year.

To address that shortcoming, on-line user-generated contents (UGC) have become widely used. The meanings of UGC vary among fields. Herein, UGC primarily refers to various on-line services such as social media posts (e.g., Twitter), search query logs (e.g., Google) and on-line shopping records. As new resources to catch and predict flu outbreaks, UGCs are attracting attention. Especially, several UGCs such as Google [3], Twitter [4], and Wikipedia [5] are used. More recently, the manner of UGC use has been refined. One study proposed a mode of selecting queries [6] and a mode of using defective UGC data for economically developing countries [7]. Although various methods exist based on UGC, most of them share one shortcoming: reliance on a single resource. As examples of using various UGC, Santillana et al. [8] used Twitter, Google Trends and flu report. Nevertheless, little is known about comparisons among resources, such as which UGC is the best, which combination of multiple UGCs works well, and the nature of each UGC. Much room exists for the study of multiple UGC handling.

This study uses resources of five kinds; (1) past flu patients, (2) social media posts, (3) search query logs, (4) shopping service query logs, and (5) Q&A service query logs from 2013–2018 (Figure 1). Furthermore, by application of linear and non-linear regression, we predict the number of flu patients in the divided term into thirds between 2015–05–25 and 2018–05–21 and discuss the properties of the respective resources.
This paper’s main contributions are the following:

- This flu prediction model incorporates the greatest number of UGCs as predictors.
- Results show that Huber Regression, which is robust against outliers, is suitable for flu prediction using UGC contents.
- Details of the nature of UGCs are discussed.

Related Work
Studies predicting ILI patient rates/numbers with the flu can be classified into the following three themes: What resources have been used?, How have queries been selected? and What models have been applied?

- What resources have been used?
  This question represents one of the important topics in the fields of infodemiology and infoveillance [9]. For the prediction of ILI rates, UGC data over search engines [3, 8, 10, 11, 12] and social networking services [4, 8, 13, 14, 15, 28] have been generally used. Discussions about which service brings more useful resources, search engines or Twitter, have occurred in earlier reports [5, 16, 17]. Aside from UGC data, many studies use various resources for improving models: Wikipedia [5], historical data [2, 10], weather data [18, 19], and self-reporting mobile app [20]. Some studies use various resources together [8, 10, 21, 22]. We make the ensemble model combining five more independent resources than previous studies including query logs about online shopping and Q & A service, never been used. Our research then aims to find the characteristic of each resource, which we use when making the influenza prediction model.

- How have queries been selected?
  As utilizing UGC data concerning a specific topic over search engines and social networking services, it is an important task to select appropriate queries because the
performance would be highly dependent on the task. For selecting suitable queries for infectious diseases, it is general to use a method based on correlation between the ILI rate and the volumes of queries. For example, the method using Google Correlate [23] and the one using word embedding [6] have been developed. Our research uses the commonly used method, correlation between the ILI rate and the volumes of queries.

- What models have been applied?
Prediction of the ILI rate frequently uses linear regression because it is a simple model and achieves measurable prediction. Additionally, various models have been proposed to apply flu prediction: the ARIMA model [24], Random Forest [19, 24], disease models such as IDEA model [25], LSTM [22] and Bayesian model [11].

Methods

Datasets
For predicting the number of flu patients in a week, we use five resources as features for 2013-10-12 through 2018-05-21. Five resources are past flu patients (National Institute of Infectious Diseases (NIID)), Search Engine (Yahoo! Japan), Social Networking Service (Twitter), On-line shopping service (Yahoo! Shopping (Japan)) and Q&A service (Yahoo! Chiebukuro) in Japan. We show the queries examples in Table 1.

- Flu patients:
The National Institute of Infectious Diseases (NIID) [29] reports data on the weekly number of patients with ILI symptoms in Japan. NIID reports information related to influenza every week through infectious disease weekly report (IDWR) [30]. These reports have a delay of about 7 days attributable to the time necessary for aggregating clinical information. We use the number of ILI patients as past flu patients as resources and the correct data for our experiments.

- Search Engine:
We use queries in Yahoo! Japan search [31], which many people use in Japan. We extract words as candidate queries: the top 50 words with the highest weights in tf-idf value and the top 100 words with the highest frequencies in tweets including “I–N–FU–LU–E–N–ZA” (“influenza”) and “I–N–FU–LU” (“influ” is the abbreviation of influenza in Japan) from 2013/10/02 through 2015/05/10 is used to select queries for use. From these words, we select 13 words for which the correlation coefficients between the number of search query logs using these candidate queries and the actual number of flu patient is greater than 0.70, as queries.
• Social Networking Service:
We use posts in Twitter [32], one of social networking services. With the same method as search engine, we select queries from candidate queries. We select 18 words for which the correlation coefficient is greater than 0.75.

• On-line Shopping:
We use queries in Yahoo! Shopping [33], one of on-line shopping services. We use the different method from that of search engine because it is assumed that words different from social networking service are used when the flu is caught. We arbitrarily select 10 words related to the flu.

• Q & A Service:
We use queries in Yahoo! Chiebukuro [34], one of popular Q & A services in Japan. The same method as the queries selection in on-line shopping service is used. We arbitrarily select 9 words related to the flu.

A summary of our resources and examples of queries are represented in Table 1 and Table 2. A volume example of five resources is shown in Figure 2.

Table 1. Summary of resources: queries how to select, examples of the query and the number of features

| Method of selection | Example of queries | Number of features |
|---------------------|--------------------|--------------------|
| (a) Past flu patients | 「高熱」 ('high fever') 「いんふる’ ('influ' in hiragana) | 52 |
| (b) Search query logs (Yahoo! Japan) | Select words as queries with correlation coefficient larger than 0.70 | 「兄」 ('big brother') 「辛い’ ('painful') |
| (c) Social media posts (Twitter) | Select words as queries with correlation coefficient larger than 0.75 | 「空気清浄機’ ('air purifier') 「マスク’ ('mask') |
| (d) Shopping query logs (Yahoo! Shopping) | Arbitrarily select words related to flu patients | 「インフル’ ('influ') 「A型インフルエンザ’ ('influenza A virus') |
| (e) Q&A Service logs (Yahoo! Chiebukuro) | Arbitrarily select words related to flu patients | 9 |
(a) Past Flu Patients

(b) Search Engine: インフル ('influ')

(c) SNS：インフル ('influ')

(d) On-line Shopping : 風邪薬 ('cold medicine')
Figure 2. Examples of time series about original data in each resource: (a) Past flu patients (b) Search Engine ‘インフル (influ)’, (c) SNS ‘インフル (influ)’, (d) Shopping service ‘風邪薬 (Cold medicine)’, (e) Q&A service ‘インフル (influ)’.

Model

We selected four machine learning algorithms to apply in this study: LASSO regression, Huber regression, Support Vector Machine regression with Linear kernel (SVR), and Random Forest. Aside from Huber regression, each was chosen for simplicity. Each is known to predict flu outbreaks. Huber regression is robust against outlier response variables. We regard this as suitable for UGC data, which are extremely noisy.

- **Lasso Regression:**
  Lasso regression, is one of regression methods, performs both variable selection and regularization by adding Lasso regularization when the parameters are fitted. This method is used in many situations because a sparse solution is obtained and is possible to select some variables from many variables.

  \[
  \mathbf{y} = \mathbf{c} \mathbf{\beta} + \mathbf{\epsilon} \\
  \mathbf{\beta} = \arg\min_{\mathbf{\beta}} (\|\mathbf{y} - \mathbf{X} \mathbf{\beta}\|_2^2 + \lambda \|\mathbf{\beta}\|_1)
  \]

  \(\mathbf{y}\) is observation vector, \(\mathbf{X}\) is feature vector, \(\mathbf{\beta}\) is regression variable vector and \(\mathbf{\epsilon}\) error vector.

- **Huber Regression:**
  Huber Regression is one of robust regression methods, which are strong against outliers not following other observed patterns. Huber Loss function is used in the parameter fitting, not the common squared loss function. Huber Loss function is described below:

  \[
  a = \frac{\|\mathbf{y} - \mathbf{X} \mathbf{\beta}\|_1}{\sigma}
  \]

  \[L_\delta(a) = \begin{cases} 
  a^2 & (|a| \leq \delta) \\
  2|a| - 1 & (|a| > \delta)
  \end{cases}
  \]
is used as $\delta$ parameter of the function. This function has the feature to decrease loss value of outliers.

### Table 2. Summary of queries, which we select in each service

| Search query logs (Yahoo! Japan) | Social media posts (Twitter) | Shopping query logs (Yahoo! Shopping) | Q&A Service logs (Yahoo! Chiebukuro) |
|---------------------------------|------------------------------|--------------------------------------|--------------------------------------|
| インフル (flu in Katakana)      | インフル (flu)                | インフルエンザ (influenza)            | インフル (flu)                        |
| いんふる (flu in Hiragana)      | インフルエンザ (influenza)     | インフル マスク (mask)               | インフルエンザ (influenza)            |
| インフルエンザ (influenza in Katakana) | インフル 元気 (flu fine)   | インフル 手 (flu hand)               | タミフル (tamiflu)                   |
| いんふるえんざ (Influenza in Hiragana) | インフル 心配 (flu worry) | インフル 熱 (flu fever)             | 風邪 (cole)                          |
| マスク (mask)                   | インフル 体調 (flu physical condition) | インフル 微熱 (flu slight fever)  | 熱 (fever)                           |
| 解熱 (fever reduction)          | インフル 大変だ (flu serious) | インフル ゆっくり (flu slowly)      | 体調 (physical condition)            |
| 学級閉鎖 (class closure)       | インフル 汗 (flu sweat)       | インフル 帰る (flu go back)         |                                      |
| 風邪をうつす (have a cold)      | インフル 流行 (flu epidemic)  | インフル 流行 (flu epidemic)        |                                      |
| インフル 薬 (flu medicine)      | インフル 流行 (flu epidemic)  | インフル 流行 (flu epidemic)        |                                      |
| インフル 症状 (flu symptom)     | インフル オール (flu painful) | インフル 兄 (flu big brother)       |                                      |
| インフル 潜在期間 (flu potential period) | インフル 薬 (flu medicine)   | インフル 薬 (flu medicine)          |                                      |
|                              | インフル 症状 (flu symptom)   | インフル 症状 (flu symptom)         |                                      |
|                              | インフル 学校 (flu school)    |                                      |                                      |
Support Vector Machine Regression with Linear kernel (SVR):

Support Vector Machine Regression (SVR) is an extension of Support Vector Machine to regression, based on the idea of margin maximization. The method has the feature to implicitly map their inputs into feature spaces. The regression equation of SVR is described below:

\[
K(x^i, x^j) = \phi(x^i)\phi(x^j)
\]

\[
f(x^j) = \sum_{i=1}^{n} (\alpha_i - \alpha_i^*) K(x^i, x^j) + c
\]

\(\phi(x^i)\) is the feature vector, \(K(*)\) is Kernel function and \(\alpha_i, \alpha_i^*\) are lagrange multipliers.

Random Forest (RF):

Random Forest (RF) approach has been used in several public health studies such as the prediction of deer mouse population dynamics, not only influenza studies. This approach is a tree-based method that stratifies or segments the predictor space into several simple regions. It is frequently used to analyze variable importance.

Experimental Settings

We use available UGC data for prediction of the number of flu patients in one week. We then use the past flu patients data from 2 weeks to 53 weeks before the predictive point because the report of flu patients in Japan is announced in about one week. Therefore, one year’s flu patient data are used as features for prediction. All features are applied to standardization.

We assess the predictive performance for three flu seasons (from 2015-05-25 to 2016-05-22, from 2016-05-23 to 2017-05-21 and from 2017-05-22 to 2018-05-21), each being a year-long period. We use all data from 2013-10-02 as training data that are available prior to each data point being predicted.

Evaluation Metrics

This report describes three evaluation metrics to compare predictive performance: the coefficient of determination \(R^2\), mean absolute error (MAE), and mean absolute percent error (MAPE). Actually, \(R^2\) is a measure of how well predicted values conform to true values. MAE is a measure of the average magnitude of difference between predicted and true values. MAPE is a measure of the average magnitude of the difference percentage between predicted and true values. These are defined as shown below.

\[
R^2 = \frac{\sum_{t=1}^{n}(F_t - A_t)^2}{\sum_{t=1}^{n}(A_t - (A_t))^2}
\]

\[
MAE = \frac{\sum_{t=1}^{n}|F_t - A_t|}{n}
\]
MAPE = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{F_t - A_t}{A_t} \right| \times 100 \%(\%)

Therin, \( n \) denotes the sample number, \( A_t \) denotes true values, and \( F_t \) represents predicted values. \( R^2 \) is the most important indicator in terms of flu prediction: it shows how well a model fits and the accuracy of prediction in the epidemic season.

**Results**

Table 3 shows the performance of the respective methods and terms for prediction, as measured for each evaluation metric. The model under Huber Regression had the best performance each year in terms of \( R^2 \) and MAE. However, in terms of MAPE, the model under Random Forest showed the best performance each year. Figure 3 presents plots of predicted flu values from 2016–05 through 2017–05 using four methods. Given the nature of evaluation metrics, the model under Huber Regression outperforms other models, especially during the epidemic period (December–March). The model under Random Forest achieves stable prediction irrespective of the epidemic period or non-epidemic period. Each model and each feature based on this result are assessed below.

Huber Regression, which achieves the highest accuracy for two metrics, is a modified model in terms of the loss function. It is therefore robust against outlier objective variables. This model also has some degree of robustness against outlier explanatory variables. These experiments use outlying observation values in some search query logs and zero values for a period of time because of bad Twitter crawling conditions that occur as a result of the use of many resources. These difficulties actually lead to good results of the model under Huber Regression. Some difficulties such as sharply increased numbers of accesses and change in crawling are always present. Therefore, using Huber Regression to predict infectious diseases such as influenza is useful in practice.

Prediction using Random Forest has higher accuracy than Huber Regression as measured by MAPE. In temperate areas such as Japan, flu patients during non-epidemic terms are around 1,000. When one variable changes slightly when using the method of regression, the prediction value can vary greatly. MAPE similarity reflects large value changes. Consequently, the model under Random Forest outputs stable values irrespective of non-epidemic terms and gives good results in terms of MAPE.

The model under Huber Regression is more important and suitable for practical use than under Random Forest because the epidemic prediction term is more important than the non-epidemic term.
Table 3. Accuracy of four models used for flu prediction

|                  | 2015/05 – 2016/05 |           | 2016/05 – 2017/05 |           | 2017/05 – 2018/05 |           |
|------------------|-------------------|-----------|-------------------|-----------|-------------------|-----------|
|                  | $R^2$      | MAE       | MAPE              | $R^2$      | MAE       | MAPE              | $R^2$      | MAE       | MAPE              |
| Lasso Regression | 0.488     | 30481.20  | 3004.88           | 0.676     | 19138.73  | 1801.58           | 0.572     | 24251.58  | 433.45            |
| Huber Regression | 0.907     | 8457.69   | 242.54            | 0.889     | 6359.84   | 85.93             | 0.917     | 7949.70   | 42.94             |
| SVR (Linear kernel) | 0.693   | 15083.25  | 199.74            | 0.887     | 12113.98  | 76.17             | 0.619     | 22192.46  | 116.68            |
| Random Forest    | 0.718     | 13857.41  | **105.23**        | 0.864     | 10628.23  | 117.93           | 0.823     | 12240.59  | **39.19**         |

(a) Lasso regression

(b) Huber regression
Figure 3. Comparative flu prediction plot of four models: (a) Lasso regression, (b) Huber Regression, (c) SVR, (d) Random Forest

Discussion

Effect of respective features
Table 4 shows the number of flu patients predicted using the model under Huber Regression with all resources except one resource to validate respective resources contributions. The model with all resources except Twitter resource achieves higher accuracy than all resources for 2017-05 through 2018-05 because tweet crawling does not work well during this period.

Table 4 also shows different degrees of effectiveness among years and features, except for past flu patients. Results show that making a consistently useful model for
predicting flu outbreaks is difficult. However, results show that the past numbers of flu patients are important predictive data.

Table 5 presents prediction results for the number of flu patients using the Autoregressive integrated moving average (ARIMA) model with only the number of flu patients as a resource. Results from Table 5 demonstrate that sufficient accuracy for influenza prediction can be achieved using only the past number of flu patients. The model with all resources achieved better results than those using only one resource, but it is not certain whether the cost of using all resources to produce a marginally better model in some cases is appropriate for improved prediction accuracy overall.

From these results, we infer that social media posts and search query logs are useful for prediction in any country with unstable sources of public health information (e.g. past flu patients), such as economically developing countries. However, these resources present fewer opportunities (such as flu prediction time lag modification) for use in countries with public health information related to annual cycle infection.
Change point analysis
To ascertain whether the trend of time series on any resources is reflected in the
trend of flu patient count, or not, we use Bayesian change point method [26,27].
Bayesian change point analysis can be used to detect signals related to subtle
changes within time series data. This method is used widely for various fields: interest
rate data, cancer–related gene expression data [27], and some resource data
(Wikipedia, Twitter, search query) for flu detection [5]. This method calculates change
point probabilities $p \in [0,1]$ of each point $i$ on the basis of the hypothesis that each
observation point is independent. With the partition of time series $\rho = (U_1, U_2, ..., U_n)$,
where $n$ is the number of observations and $U_i = 1$ indicates a change point at
position at $i + 1$. The transition probability $p$ at the position $i + 1$ is obtained from
below:

$$
\frac{p_i}{1 - p_i} = \frac{P(U_i = 1|X, U_j, j \neq i)}{P(U_i = 0|X, U_j, j \neq i)}
$$

$$
= \frac{[\int_0^\lambda p^c(1 - p)^{n-b-1}dp] \left[ \int_0^{\frac{b}{2}} w^{b/2} dw \right]}{[\int_0^\lambda p^{b-1}(1 - p)^{n-b}dp] \left[ \int_0^{\frac{(b-1)/2}{(W_1 + B_1 w)^{(n-1)/2}} dw \right]}
$$

$W_0$ and $W_1$ are the within blocs sums of squares obtained when $U_i = 1$ and $U_i = 0$, respectively. $B_0$ and $B_1$ are the between blocs sums of squares obtained. $X$ is the
data. $\lambda$ and $\gamma$ are hyper–parameters, which are taken from $[0,1]$. $j$ indicates ending
position and $b$ is the number of blocks in the partition. MCMC updates the various
sums of squares ($W_0$, $W_1$, $B_0$ and $B_1$) in each step.

We use the R package “bcp” ver. 4.0.2 [26], which implements Bayesian change point
analysis using a complex Markov Chain Monte Carlo (MCMC) approximation. With a
view to ascertaining whether change points in flu patients match those of internet–
based resources, we regard any point for which the probability of a change occurring exceeds 50% as a change point. Change points of web–based resources that occurred
from 1 week before to 1 week after a change point of the time series for flu patients
are regarded as true matching change points. We calculate Sensitivity and the
positive predictive value (PPV) to validate the resource effectiveness. This
calculation uses matching change points (true positive) and change points detected
for flu patient data, but not for web–based resources (true negative). It also uses
change points detected for web–based resources but not for flu patient data (false
positive). Sensitivity and PPV are defined as shown below.

$$
\text{Sensitivity} = \frac{\text{true positive}}{\text{true positive} + \text{false negative}} \times 100 \%
$$

$$
\text{PPV} = \frac{\text{true positive}}{\text{true positive} + \text{false positive}} \times 100 \%
$$
For the change point analysis, we set the number of MCMC iterations as 500 and hyper-parameter $\lambda$ and $\gamma$ as 0.1. We then select three queries, which are the highest correlation coefficient between each query and the ILI rate, from each resource.

Results are presented in Table 6. Two metrics about social media posts are bad because of the unstable amount of tweets between 2016–05 and 2017–05. However, this high value of two metrics related to search query logs and social media posts for three years represents these resources as a good predictor. Presumably, two resources are stable contributions to flu prediction: Search query logs and Social media posts.

For shopping query logs, PPV is high but Sensitivity is low because this time series reflect few behaviors; they capture little change points of flu patients. For Q&A service logs, Sensitivity is high but PPV is low. This result demonstrates that the time series related to Q&A service logs capture the change points for flu patients. However, results capture the flatness of the times series as change points because Q&A service logs include much noise.

| Table 6. Sensitivity and PPV for four resources |
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Regarding resource characteristics, shopping query logs show few behaviors; Q&A service logs have much noise.

Some earlier studies include discussions of useful resources such as search queries or Twitter [5, 16]. It appears difficult to conclude which one is better. Results presented herein suggest that the usefulness of respective resources for flu prediction depends on the year and shows no great difference. Our ensemble model produces reliable, robust, and accurate estimates. However, some models that do not include one of the resources show better scores for some years because of crawling malfunctions. In some countries with sufficient public health information, the use of a single UGC (search query or Twitter) in addition to past flu patient data can produce a highly accurate prediction model. On the other hand, for countries with insufficient public health organizations and information, the UGC is expected to have a proportionally higher value as a flu prediction model component.

Conflicts of Interest
The authors have no conflicts of interest directly relevant to the content of this article.

References
1. World Health Organization. 2018. Influenza (Seasonal): Fact sheet URL: https://www.who.int/news-room/fact-sheets/detail/influenza-(seasonal) [accessed 2019-07-04]
2. Zhang, Jie, and Kazumitu Nawata. A comparative study on predicting influenza outbreaks. Bioscience trends; Nov 20 2017;11(5):533-541. PMID: 29070762
3. Ginsberg J, Mohebbi MH, Patel RS, Brammer L, Smolinski MS, Brilliant L. Detecting influenza epidemics using search engine query data. Nature. Feb 2009;457(7232):1012-1015. | doi:10.1038/nature07634
4. Aramaki E, Maskawa S, Morita M. Twitter catches the flu: detecting influenza epidemics using Twitter. The Conference on Empirical Methods in Natural Language Processing (EMNLP); July 27-31, 2011; Edinburgh, Scotland, UK. Association for Computational Linguistics; 2011;1568-1576. ISBN: 978-1-937284-11-4
5. Sharpe JD, Hopkins RS, Cook RL, Striley CW. Evaluating Google, Twitter, and Wikipedia as tools for influenza surveillance using Bayesian change point analysis: a comparative analysis. JMIR public health and surveillance.; 2016;2(2):e161. PMID: 27765731
6. Lampos V, Zou B, Cox IJ. Enhancing feature selection using word embeddings: The case of flu surveillance. In Proceedings of the 26th International Conference on World Wide Web; Apr 3, 2017; Perth, Australia. International World Wide Web Conferences Steering Committee; 2017; 695-704. ISBN: 978-1-4503-4913-0
7. Zou B, Lampos V, Cox I. Multi-task learning improves disease models from web search. In Proceedings of the 27th International Conference on World
Santillana M, Nguyen AT, Dredze M, Paul MJ, Nsoesie EO, Brownstein JS. Combining search, social media, and traditional data sources to improve influenza surveillance. PLoS computational biology.; Oct 29 2015;11(10):e1004513. doi:10.1371/journal.pcbi.1004513

Eysenbach, Gunther. Infodemiology and infoveillance: framework for an emerging set of public health informatics methods to analyze search, communication and publication behavior on the Internet. Journal of medical Internet research 2009;11(1):e11. doi: 10.2196/jmir.1157 PMID: 19329408

Shihao Yang, Mauricio Santillana, S. C. Kou Accurate influenza epidemics estimation via ARGO. In Proceedings of the National Academy of Sciences Nov 2015;112(47):14473-14478. doi: 10.1073/pnas.1515373112

Xu Q, Gel YR, Ramirez Ramirez LL, Nezafati K, Zhang Q, et al. Forecasting influenza in Hong Kong with Google search queries and statistical model fusion. PLOS ONE 2017;12(5): e0176690. Doi: 10.1371/journal.pone.0176690

Clemente L, Lu F, Santillana M. Improved Real-Time Influenza Surveillance: Using Internet Search Data in Eight Latin American Countries. JMIIR Public Health Surveill 2019;5(2):e12214. Doi: 10.2196/12214 PMID: 30946017

Paul MJ, Dredze M, Broniatowski D. Twitter Improves Influenza Forecasting. PLOS Currents Outbreaks. Oct 28 2014;6. doi: 10.1371/currents.outbreaks.90b9ed0f59bae4ccaa683a3986d9117.

Wakamiya S, Kawai Y, Aramaki E. Twitter-Based Influenza Detection After Flu Peak via Tweets With Indirect Information: Text Mining Study. JMIIR Public Health Surveill 2018;4(3):e65. doi: 10.2196/publichealth.8627 PMID: 30274968

Alessa A, Faezipour M Preliminary Flu Outbreak Prediction Using Twitter Posts Classification and Linear Regression With Historical Centers for Disease Control and Prevention Reports: Prediction Framework Study JMIIR Public Health Surveill 2019;5(2):e12383 doi: 10.2196/12383 PMID: 31237567

Nagar R, Yuan Q, Freifeld CC, Santillana M, Nojima A, Chunara R, Brownstein JS. A Case Study of the New York City 2012-2013 Influenza Season With Daily Geocoded Twitter Data From Temporal and Spatiotemporal Perspectives. J Med Internet Res 2014;16(10):e236. doi:10.2196/jmir.3416 PMID: 25331122

Signorini A, Segre AM, Polgreen PM. The Use of Twitter to Track Levels of Disease Activity and Public Concern in the U.S. during the Influenza A H1N1 Pandemic. PLOS ONE 2011;6(5): e19467. doi:10.1371/journal.pone.0019467

Anice C. Lowen, John Steel. Roles of Humidity and Temperature in Shaping Influenza Seasonality. Journal of Virology Jun 2014;88(14):7692-7695. doi: 10.1128/JVI.03544-13

Wu, Hongyan, Cai Yunpeng, Wu Yongsheng, Zhong Ren, Li Qi, Zheng Jing, Lin Denan, Li Ye. Time series analysis of weekly influenza-like illness rate using a
one-year period of factors in random forest regression. BioScience Trends Jul 2017;11(3):292-296. doi: 10.5582/bst.2017.01035

20. D. Paolotti, A. Carnahan, V. Colizza, K. Eames, J. Edmunds, G. Gomes, C. Koppeschaar, M. Rehn, R. Smallenburg, C. Turlbing, et al. Web-based participatory surveillance of infectious diseases: the Influenzanet participatory surveillance experience. Clin Microbiol Infect. Jan 2014;20(1):17-21. doi: 10.1111/1469-0691.12477

21. Lampos, V. et al. Advances in nowcasting influenza-like illness rates using search query logs. Sci. Rep. 5. 2015;5:12760. doi: 10.1038/srep12760

22. Volkova S, Ayton E, Porterfield K, Corley CD. Forecasting influenza-like illness dynamics for military populations using neural networks and social media. PLOS ONE 2017;12(12): e0188941. doi: 10.1371/journal.pone.0188941

23. Dalum Hansen N, Mølbak K, Cox II, Lioma C. Seasonal Web Search Query Selection for Influenza-Like Illness (ILI) Estimation. In Proceedings of the 40th International ACM SIGIR Conference on Research and Development in Information Retrieval. Aug 7 2017:1197-1200. ISBN: 978-1-4503-5022-8 doi: 10.1145/3077136.3080760

24. Kane, Michael J., Natalie Price, Matthew Scotch, and Peter Rabinowitz. Comparison of ARIMA and Random Forest time series models for prediction of avian influenza H5N1 outbreaks. BMC bioinformatics 2014;15(1):276. doi:10.1186/1471-2105-15-276

25. Tahmina Nasserie, Ashleigh R Tuite, Lindsay Whitmore, Todd Hatchette, Steven J Drews, Adriana Peci, Jeffrey C Kwong, Dara Friedman, Gary Garber, Jonathan Gubbay, David N Fisman, Seasonal Influenza Forecasting in Real Time Using the Incidence Decay With Exponential Adjustment Model, Open Forum Infectious Diseases. 2017;4(3):ofx166, doi: 10.1093/ofid/ofx166

26. Erdman C, Emerson JW. bcp: an R package for performing a Bayesian analysis of change point problems. Journal of Statistical Software. Dec 18 2007;23(3):1-3. doi: 10.18637/jss.v023.i03

27. Erdman C, Emerson JW. A fast Bayesian change point analysis for the segmentation of microarray data. Bioinformatics. Jul 29 2008;24(19):2143-8. doi: 10.1093/bioinformatics/btn404

28. Santos JC, Matos S. Analysing Twitter and web queries for flu trend prediction. Theor Biol Med Model. 2014,. doi: 10.1186/1742-4682-11-S1-S6.

29. Niid.go.jp. [2019-07-31]. National Institute of Infectious Diseases, Japan https://www.niid.go.jp/niid/en/

30. Niid.go.jp. National Institute of Infectious Diseases, Japan; [2019-07-31]. IDWR Surveillance Data Table https://www.niid.go.jp/niid/en/surveillance-data-table-english/

31. Yahoo! Japan [2019-07-31], https://www.yahoo.co.jp

32. Twitter [2019-07-31], https://twitter.com

33. Yahoo! Shopping [2019-07-31], https://shopping.yahoo.co.jp/

34. Yahoo! Chiebukuro [2019-07-31], https://chiebukuro.yahoo.co.jp/