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PREDICTING TECHNOLOGY SUCCESS BASED ON PATENT DATA, USING A WIDE AND DEEP NEURAL NETWORK AND A RECURRENT NEURAL NETWORK

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Abstract

The temporal dynamic growth of technology patents for a time sequence is a major indicator to measure the technology power and relevance in innovative technology-based product/service development. A new method for predicting success of innovative technology is proposed based on patent data and using Neural Networks models. Technology patents data are extracted from the United States Patent and Trademark Office (USPTO) and used to predict the future patent growth of two candidate technologies: "Cloud/Client computing" and "Autonomous Vehicles". This approach is implemented using two Neural Networks models for accuracy comparison: a Wide and Deep Neural Network (WDNN) and a Recurrent Neural Network (RNN). As a result, RNN achieves a better performance and accuracy and outperforms the WDNN in the context of small datasets.

Keywords: Innovative product development, forecasting technology success, patent analysis, machine learning.

Introduction

Product development consists of methods and processes focused on value creation through the development of new and innovative technology-based products. The traditional technical aspects are involved such as engineering design techniques, cost reduction, increase in product quality, etc. However, predicting technologies success is a crucial need and a prerequisite step for investments in product development and value creation. For instance, (Jneid & Saleh, 2015) have stated that for start-ups facing a competitive environment, innovation is a key factor contributing to their success. They presented a new approach based on co-innovation which provides a method for co-innovation and co-creation of values by convergence and collaboration. Furthermore, organizations seek to enhance the Research and development (R&D) activities by increasing the R&D investments on new patents technologies (Hall, 2004). Technology patents can be used as a significant factor for measuring success and relevance in technology-based product

development, and therefore, patents growth of a technology can be used as a major indicator to predict its power and its impact on value-creation.

Accordingly, the main problematic of this study is to examine how technology success can be forecasted based on patent analysis, using a convenient prediction tool while considering data availability and how to prioritize several trending technologies in order to identify the most appropriate ones for a given investment project.

Therefore, in this paper, we initially propose a novel model for forecasting technology success and predicting patents growth, based on two Neural Network models for comparison purpose: a Wide and Deep Neural Network and a Recurrent Neural Network. Noting that according to our research, this approach has not been implemented so far when forecasting patents growth in this specific context.

Literature review

Technologies Patents play a critical role in fostering innovation and making decisions (Chen, et al., 2017). Patents data can be used and analyzed to predict promising technology, in order to provide reliable knowledge for decision making (Cho, et al., 2018). Patent expansion potential and patent power are considered as technology scope indicators (Altuntas, et al., 2015). In addition, the National Science Board highlights the importance of patents counts and patents citations (National Science Board, 2014) in measuring the innovation value and the knowledge flows. Professor Bronwyn H. Hall (Hall, 2004) identified a positive correlation between the patents grant growth and the industrial R&D, which consequently increases the total R&D.

Patent-based technology forecasting methods:

Patent-based technology forecasting has been considered a reliable method for finding technology scope, identifying trending technologies and improving decision-making.

For instance, a patent analysis has been elaborated to quantitatively forecast the technology success in the context of patent expansion potential, patent power, technology life cycle and diffusion potential (Dereli & Kusiak, 2015). Cho, Lim, Lee, Cho and Kyung-InKang analyzed patents data to predict promising technology fields in the building construction (Cho, et al., 2018).

In addition, patent data have been employed in a matrix map and in the quantitative method 'K-medoids clustering, in order to predict the vacant technologies in the management of technology field (Jun, et al., 2012). Furthermore, a machine learning approach has been proposed to detect new technologies at early stages, using several patent indicators and a multilayer neural network, while focusing on the pharmaceutical technology (Lee, et al., 2017). Kim and Lee proposed a prediction approach for multi-technology convergence based on patent-citation analysis, a neural network analysis and a dependency-structure analysis (Kim & Lee, 2017).

Research design

In the present study, the analysis of patent data is considered as a quantitative approach to assess its impact on a technology's success. Specifically, this study forecasts the future growth of patents for a given technology, using a Neural Network model. The latter is built using two separate methods for comparison purposes: a Wide and Deep Neural Network (WDNN) model and a Recurrent Neural Network (RNN) model.

Neural Network model:

The artificial neural networks are used for a dynamic (ALSHEIKH, et al., 2014), unsupervised learning (Schmidhuber, 2015) from historical data in order to estimate future values.

In this paper, the neural networks are used specifically for data classification, regression, data analysis and prediction.

Wide and Deep Neural Network model:

Generally, the more data a Neural Network can have, the more its generated predictions are accurate and reliable (Thrideep, 2017). However, Big Data analytics issues and challenges can be referred to the fast information retrieval, data representation, data processing, etc. For this reason, this Neural Network is structured as a wide and deep model in order to support such tasks, since it can handle complex large-scale data (Elaraby, et al., 2016), integrating heterogeneous input data (Najafabadi, et al., 2015). In addition, Deep learning algorithms generalize the extracted representation and the relationships in the data, by exploring new or rare features combinations by transitivity of correlations. However, deep neural network can over-generalize and extract less relevant features (Cheng, et al., 2016). For this reason, the memorization of features interactions or correlations in the historical data, the exception rules and the frequent co-occurrence of features is a crucial need to enhance the neural network prediction. Hence the importance of merging a wide linear model for learning exceptions and memorizing specific rules with a deep model for learning interactions within historical data and then generalizing the output on new data (Cheng, et al., 2016).

Recurrent Neural Network model:

RNN is a model of artificial Neural Network where its nodes are connected along sequences. Accordingly, the main reason of using this model of Neural Network is to process sequences of inputs in order to predict a sequence of outputs where these sequences can be different in lengths for different technologies (Ng, et al., 2018), which is applied in our case as well.

In addition, Gated Recurrent Units (GRU) are employed in the RNN as they tend to optimize the performance on smaller datasets (Chung, et al., 2014), which is the case of our study where the data are limited to 163 records.

The above models will be discussed in details in the following sections: Proposed methodology and Neural Network models structures.

1. Proposed methodology

The proposed methodology is illustrated with a process flow, as presented in Figure 1, covering the following main objectives: data collection, database integration, data manipulation, datasets creation, neural networks implementation, results visualization/analysis and decision-making.

It consists of 15 steps, explained in Table 1:

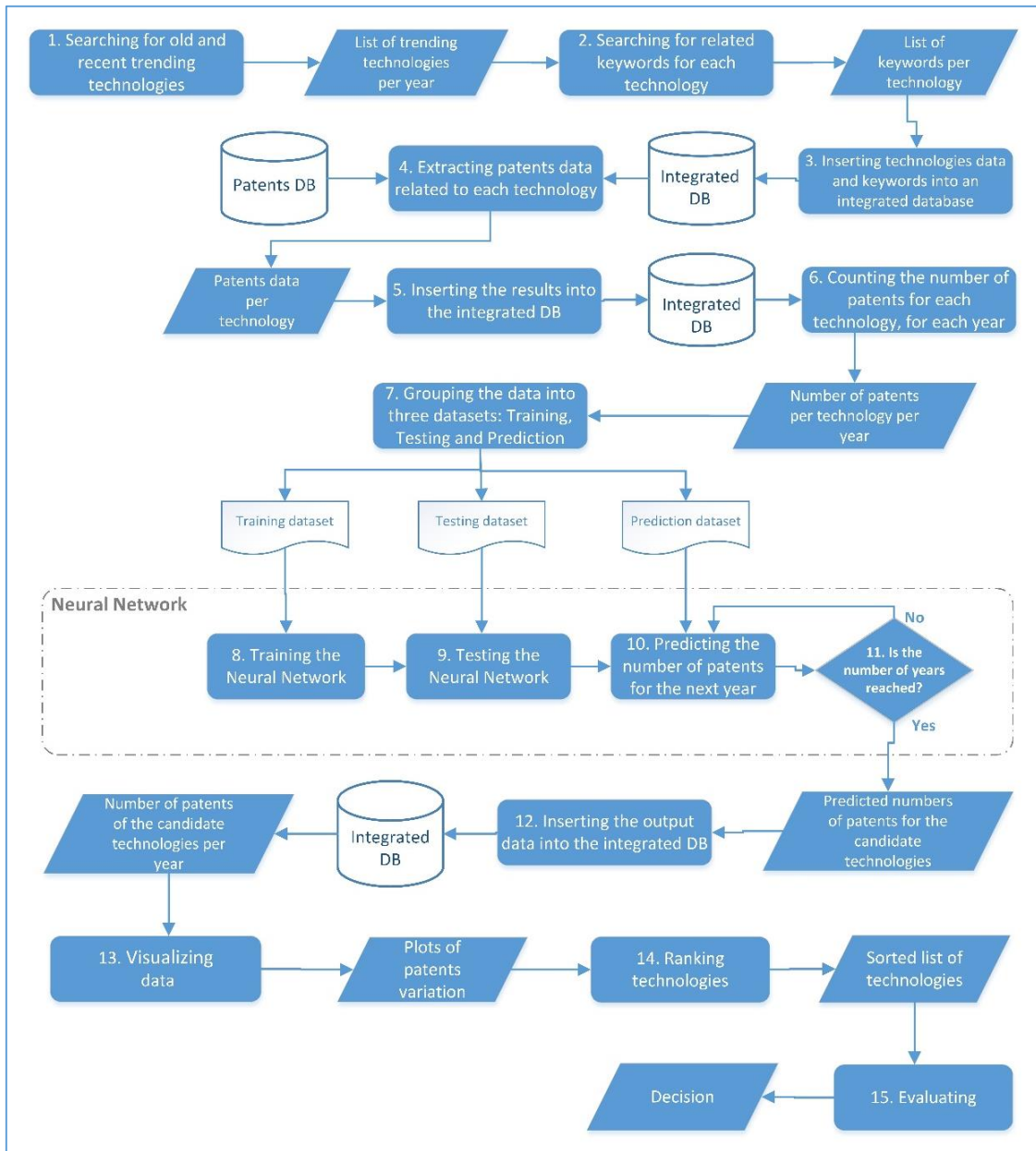


Figure 1: Methodology design.

Table 1: Methodology design steps.

Objective	Step	Description
Data Collection	Step 1	Searching for old and new trending technologies from several references.
	Step 2	Listing the related keywords for each technology.
Database integration	Step 3	Inserting these technologies' data and their related keywords into two separate tables in a new integrated database. These two tables are related according to the identifier "tech_id".

		Noting that these tables are considered as dictionary tables which the following steps will depend on.
Data Collection	Step 4	Extracting patents data related to each technology from a patent database based on keywords matching. Several patents databases could be used such as the United States Patent and Trademark Office (USPTO) database. This latter is considered among the richest intellectual property databases, it issued approximately 10 million patents so far (USPTO, 2018).
Database integration	Step 5	Manipulating and inserting data into the integrated DB.
Data manipulation	Step 6	Computing the total number of patents per technology per year.
Datasets creation	Step 7	Querying and grouping the data by year following the axis: [Year ^{-max} , ..., Year ⁻¹ , Year ⁰ , Year ¹ , ..., Year ^p]. Such as: <ul style="list-style-type: none"> - <i>max</i>: represents the maximum number of years per technology where historical data is available in the training dataset. - <i>p</i>: represents the number of years for which we are validating results in the testing dataset, and the number of years for which we are predicting results in the prediction dataset. - Year⁰: represents the most recent year in the training data set per technology, based on data availability.
Neural networks implementation	Step 8	Training the Neural Networks.
	Step 9	Testing the Neural Networks.
	Step 10	Predicting the number of patents.
	Step 11	The number of years y that we need to generate is checked at every step during the prediction phase until y is equal to p .
Database integration	Step 12	Inserting the output data of the Neural Network into the integrated database.
Results visualization and analysis	Step 13	Illustrating the patents variation in statistical graphs.
	Step 14	Ranking the candidate technologies based on their patents progress.
Decision-making	Step 15	Evaluating and prioritizing the candidate technologies based on the above ranking and based on business perspective.

2. Neural Network models structures

The Neural Networks have been built using the TensorFlow software library under Python. Tensorflow is a high level open-source API created by Google and is used for Machine Learning and deep neural network purposes (TensorFlow, 2018). As previously mentioned, two Neural Network designs are proposed based on different models:

2.1. Wide and Deep Neural Network

This Neural Network structure is based on the “DNN Linear Combined Regressor” (TensorFlow, 2018). Noting that “regression” refers to the prediction of a continuous variable as output (Bishop, 2006), in our case, the estimation of the number of patents.

Furthermore, Adagrad is used as an optimization method during the training phase, since it can handle sparse data (Ruder, 2016) and enhance the robustness of the Stochastic Gradient Descent (Dean, et al., 2012).

This Neural Network consists of the following layers:

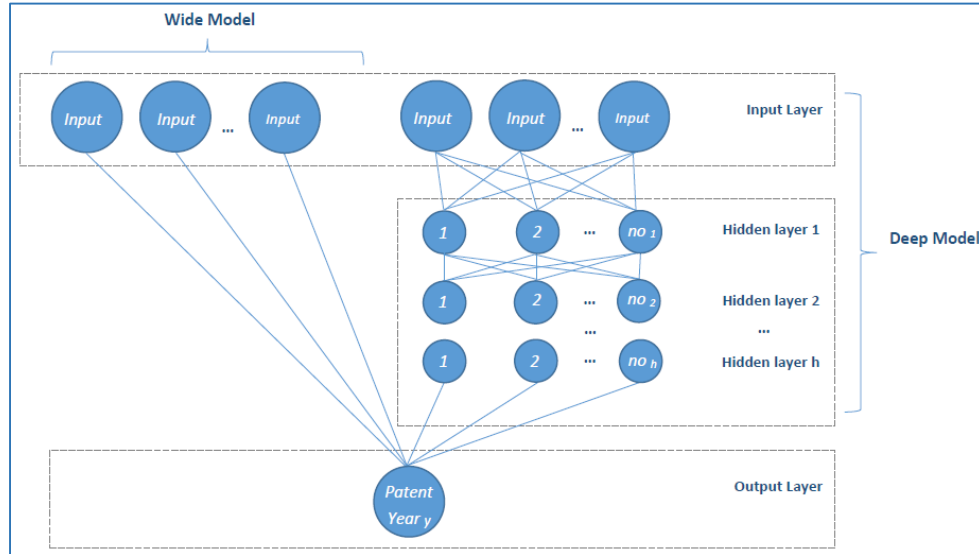


Figure 2: Wide and Deep Neural Network.

- **Input Layer:** The input layer is composed of two types of nodes:
 - Continuous number: represents the number of patents for a technology for each available year.
 - Bucket: represents ranges of the same data as the continuous number for each available year.
- **Hidden Layers:** represent the intermediary layers that can make the model more adaptable. This neural network contains a specific number h of hidden layers, and each one contains a specific number no of nodes. Noting that the hidden layers could be adjustable based on the accuracy and the loss results.
- **Output layer:** represents the data to be forecasted. The number of patents from Year₁ till Year_p will be predicted for the technology in question. Noting that in Step 10, during the prediction phase, the neural network predicts the number of patents for each year separately and in Step 11 the number of years y is checked at every step. Therefore, each predicted output is serving as input for the next prediction until the number of years y we need to generate is reached: in other words until y is equal to p .

<i>Tech</i>	Patent Year ₁
<i>Tech</i>	Patent Year ₂
<i>Tech</i>	...
<i>Tech</i>	Patent Year _p

Figure 3: The outputs of the DWNN.

2.2. Recurrent Neural Network

The RNN has been implemented for time series prediction based on an encoder-decoder sub-model using Gated Recurrent Unit (GRU) cells and based on a Sequence-to-Sequence (seq2seq) neuronal architecture, where the RNN can map a variable-length sequence of inputs (x_1, \dots, x_T) to a sequence of outputs (y_1, \dots, y_T) , by encoding this input sequence into a fixed-length vector representation and then decoding a fixed-length vector representation into the target sequence (Sutskever, et al., 2014) (Ng, et al., 2018). In this case, the input size differs according to the data availability of each technology. In addition, this Neural Network is structured as a many-to-many model, where both the input and the output represent sequences of data with same or different lengths (Ng, et al., 2018).

Furthermore, regarding the optimization method applied to minimize the cost function during the backward propagation in the training phase, the Root Mean Square Prop (RMSProp) optimizer is applied in order to speed up the gradient descent (Ng, et al., 2018).

The RNN consists of the following layers:

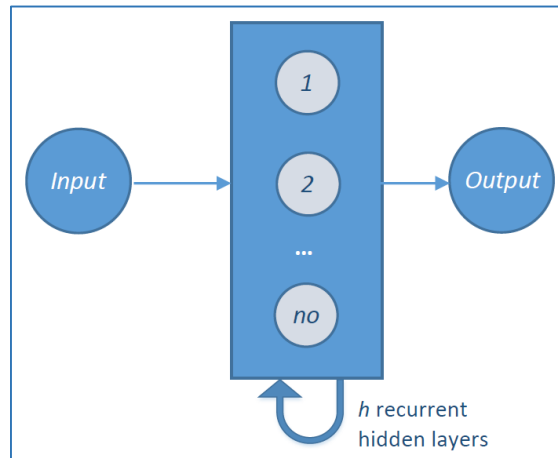


Figure 4: Recurrent Neural Network.

- **Input Layer:** The input layer takes sequences of time series data with variable-length. In addition, each row in a given dataset represents an input sequence in the RNN.
- **Hidden Layers:** This neural network can contain a specific number h of stacked recurrent cells on the depth axis and a width of no hidden units or nodes for each cell. Noting that all hidden layers can be merged into one stacked recurrent layer, since all of them have same biases and weights (De, 2018).
- **Output layer:** represents the data sequence to be forecasted. The number of patents from Year₁ till Year_p will be predicted as a sequence of p cells for the technology in question. Accordingly, in

this case, Step 11 is not needed given that the prediction of the number of patents of all y years is executed at a single step: that means $y = p$.

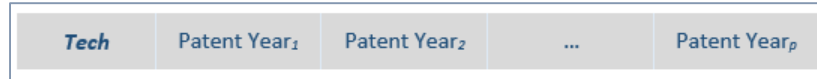


Figure 5: The output sequence of the RNN.

Experimentation

We collected patent data for 11 trending technologies over a period of time, in order to train and test the neural network. The two Neural Networks models are applied on two candidate technologies to predict the number of patents for the next five years: in this case the parameter p is equal to 5.

1. Data collection

1.1. Technologies listing

The selected technologies are listed based on several web sources, such as: IEEE (IEEE, 2016) (IEEE, 2015), Gartner (Cearley, et al., 2017), Elsevier (Peter Edelstein, 2017), Scientific American (Meyerson, 2015), MIT Technology Review (MIT Technology Review, 2018), etc. Therefore, their related keywords are extracted manually using different references, such as “thesaurus” (Thesaurus, 2013), “TechTerms” (Tech Terms, 2018), etc. and inserted in the integrated database.

1.2. Patent data Source

A CSV file containing the granted patents applications published until 2016 has been downloaded from the USPTO website and imported into the ‘Patents’ table in the database.

Therefore, given that the patents data extracted from the USPTO are not grouped or categorized by technology, a script has been developed under Python in order to extract the needed data by technology from the ‘Patents’ table, based on technologies keywords matching. Specifically, patents were categorized by technology based on the title of the patent application: the text analysis can be conducted by searching each keyword or term of each technology in the title of all patents applications (Sunghae, 2011).

Finally, the number of patents were counted and grouped by year and by technology. The result was then inserted into the ‘NumberOfPatents’ table.

The following figure represents the number of patents variation for a list of technologies:

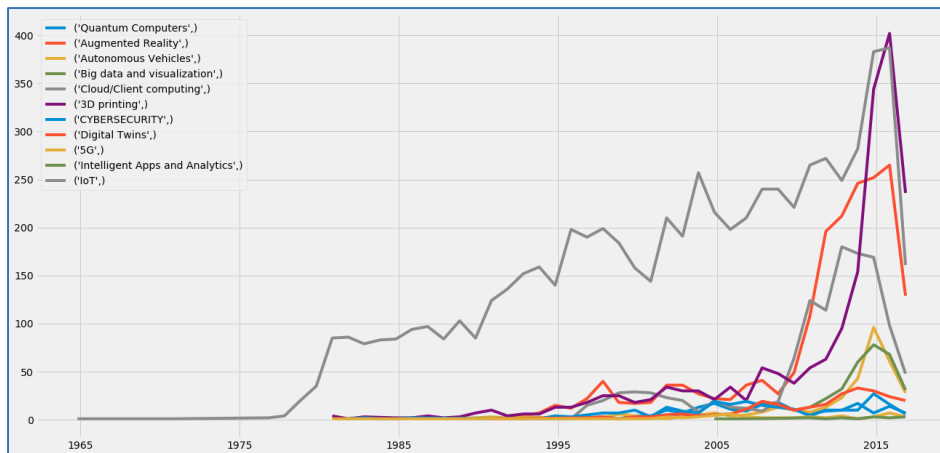


Figure 6: Number of patents variation of different technologies from 1965 to 2016.

2. Training, Testing and Prediction datasets creation

The data in the 'NumberOfPatents' table have been split manually into training and validation datasets based on the correlation between the number of patents of the technologies, since we have a limited amount of data. The following figures illustrate samples of the original data:

```
Quantum Computers,1,1,2,2,1,4,4,10,7,13,17,11,9,16,18,10,7,9,10,17,7,14,7
Augmented Reality,15,12,22,40,18,17,18,36,36,27,22,21,36,41,27,49,108,196,212,246,252,265,129
Big data and visualization,1,2,3,1,3,3,5,6,4,5,6,11,19,16,10,13,22,32,60,78,68,31,9,6
3D printing,1,4,1,3,2,2,4,2,3,7,10,4,6,6,13,13,18,25,25,18,21,34,30,30,21,34,20,54,48,38,54,63,95,154,344,402,236
CYBERSECURITY,1,2,1,1,2,1,1,1,4,3,5,7,7,10,3,13,9,7,19,16,19,15,13,11,4,10,10,10,27,16,6
```

Figure 7: A sample of the training data.

```
Autonomous Vehicles, 2,3,2,1,2,6,2,1,5,7,4,5,8,13,10,8,13,23,43,96,61,28,10,5
Cloud/Client computing,20,13,12,19,64,124,114,180,173,169,98
```

Figure 8: A sample of the testing data.

As per figure 6, 7 and 8, the number of patents of the "Autonomous Vehicles" technology in the testing dataset is correlated with the "Big data and visualization" technology in the training dataset, since the variation of their number of patents is approximately similar through the years. Moreover, the "Cloud/Client computing" technology in the testing dataset is correlated as well with the "Augmented Reality" technology that belongs to the training dataset.

Regarding the Prediction dataset, it contains the patent data related to the same technologies as the testing dataset, in order to be able to compare the predicted values with the actual values, and therefore to visualize the accuracy of the models. Accordingly, the prediction can be applied on any new technology using the most accurate implemented model.

3. Neural Networks implementation

The implemented neural networks are based on different open source tutorials. The training parameters have been tuned progressively, and the configurations in these experiments have been determined experimentally based on the best obtained results, as suggested by Chevalier (Chevalier, 2018).

3.1. Wide and Deep Neural Network

In order to implement the WDNN, we have referred to the open source tutorial of TensorFlow under GitHub (TensorFlow, 2017), with the following main parameters, as defined in the Proposed Methodology section:

```
p = 5 years; y = 1 year (as initial value); max = 45 years; n = 9; h = 5 hidden layers; no1 = 1000
nodes; no2 = 750 nodes; no3 = 500 nodes; no4 = 300 nodes; no5 = 150 nodes
```

a) Training

The training phase was processed by executing 10000 iterations, with a small learning rate equal to 0.001 in order to decrease the loss function and therefore to accelerate the training convergence (Ng, et al., 2018).

b) Validation and Prediction

In this section, the accuracy of this neural network was calculated as per the following steps and formulas:

- i. First we normalized the expected and the predicted values on a scale from 0 to 100: the highest value (*max*) in the expected values array was considered as 100, then the other expected (*expected*) and predicted (*pred*) values was normalized accordingly:

```

expected_n = expected * 100 / max
pred_n = pred * 100 / max

```

- ii. Then we calculated the absolute difference between the new normalized values of the expected and the predicted arrays:

```

diff_n = abs (expected_n - pred_n)

```

- iii. Finally the accuracy was calculated by subtracting the average difference of the obtained values from the total percentage:

```

accuracy = 100 - (mean(diff_n))

```

3.2. Recurrent Neural Network

In order to implement the Sequence-to-Sequence neural network, we have referred to the open source code of the “Signal prediction with a Sequence-to-Sequence Recurrent Neural Network model in TensorFlow” (Chevalier, 2018), with the following main parameters, as defined in the Proposed Methodology section:

```

p = 5 years; max = 45 years; n = 5; h = 2 recurrent cells; no = 250 hidden units per cell

```

a) Training

The training phase was processed by executing 1000 iterations, with a small learning rate equal to 0.001 in order to prevent divergent losses (Ravaut & Gorti, 2017) (Ng, et al., 2018).

b) Validation and Prediction

The accuracy of the RNN was calculated based on the same steps and formulas as for the WDNN.

4. Results

The graphs in the following subsections represent the obtained results for both candidate technologies in the WDNN and the RNN, illustrating the quality of the prediction, where the abscissa axis represents the time and the ordinate axis represents the number of patents.

As per the below results of the two neural networks, we note that the predicted numbers of patents for the “Autonomous Vehicles” technology are following the same pattern as the “Big data and visualization” technology, concluding that the correlation mentioned earlier between these two technologies was detected by the neural networks during the prediction phase with a certain accuracy rate. The same applies to the “Cloud/Client computing” and the “Augmented Reality” technologies.

4.1. Wide and Deep Neural Network

Table 2: Prediction accuracy for the WDNN.

Wide and Deep Neural Network

"Cloud/Client computing" (Figure 9)		"Autonomous Vehicles" (Figure 10)	
Actual or true values	Predicted Values	Actual or true values	Predicted Values
114	126	96	53
180	113	61	43
173	154	28	32
169	222	10	22
98	265	5	22
Prediction accuracy: 64.66%		Prediction accuracy: 80.41%	
Average prediction accuracy: 72.53%			

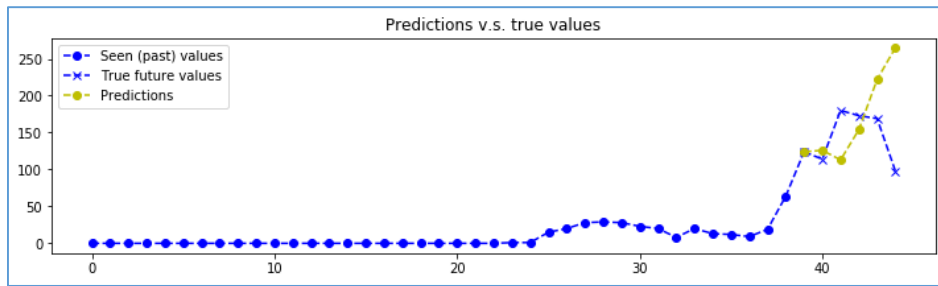


Figure 9: Actual and predicted number of patents in the WDNN for the "Cloud/Client computing" technology from 1995 to 2016.

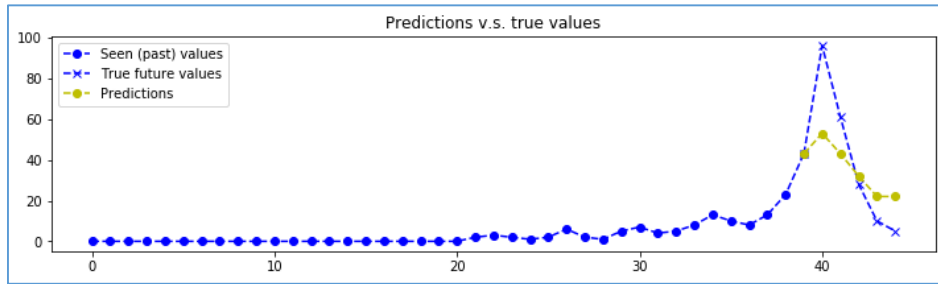


Figure 10: Actual and predicted number of patents in the WDNN for the "Autonomous Vehicles" technology from 1991 to 2016.

4.2. Recurrent Neural Network

Table 3: Prediction accuracy for the RNN.

Recurrent Neural Network			
"Cloud/Client computing" (Figure 11)		"Autonomous Vehicles" (Figure 12)	
Actual or true values	Predicted Values	Actual or true values	Predicted Values
114	187	96	69
180	234	61	67
173	241	28	34
169	251	10	11

98	129	5	11
Prediction accuracy: 65.45%		Prediction accuracy: 90.16%	
Average prediction accuracy: 77.8%			

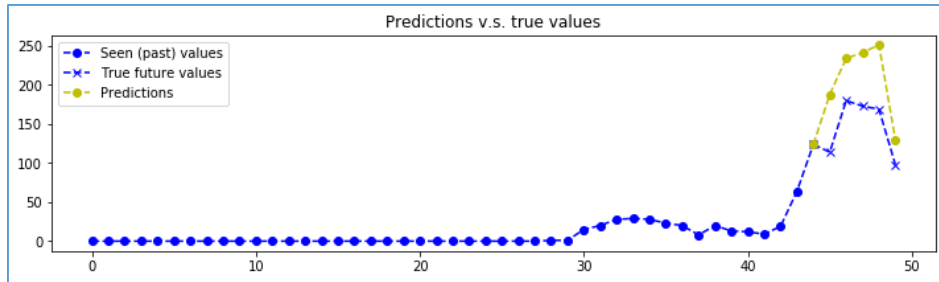


Figure 11: Actual and predicted number of patents in the RNN for the "Cloud/Client computing" technology from 1995 to 2016.

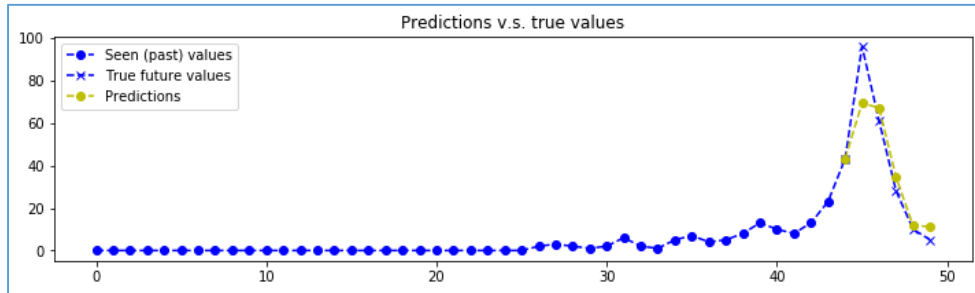


Figure 12: Actual and predicted number of patents in the RNN for the "Autonomous Vehicles" technology from 1991 to 2016.

Conclusion and discussion

The development of new and innovative technology-based products creates business value in today's economy, and therefore, forecasting technologies success becomes a crucial need. However, predicting technologies success is a complex task in terms of prediction accuracy and data availability. Accordingly, a novel method has been proposed in this paper, relying on patent analysis as a quantitative approach, and using Neural Networks models in order to measure the candidate technologies power based on the prediction of patents growth. Addressing this estimation is a necessary prerequisite before proceeding with investments.

This method has been implemented using the USPTO Patent Database, with a comparative study of two Neural Networks: a Wide and Deep Neural Network and a Recurrent Neural Network, and experimented on 11 trending technologies to train and test these neural networks then applied on two candidate technologies, "Cloud/Client computing" and "Autonomous Vehicles", for the prediction phase.

The findings showed that RNN is more performing and accurate than WDNN.

Therefore, the proposed method answers questions related to technology success and appropriate prediction models. Accordingly, it supports decision making of innovative technology-based product/service development.

This study can be further enhanced by tackling its current limitations. The most challenging task faced in our study is the access to accurate Big data, as the data are currently limited to a small dataset extracted

only from the USPTO database and based uniquely on the granted patents applications, published until 2016. In addition, patent data are categorized by technology based on keywords matching of only the title of the patent application. They can be queried as well in the application abstracts and other fields. Furthermore, future works can further evolve the proposed research design to include additional factors or dimensions affecting future technology success.

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