In [1]:
```
# Install TensorFlow
# !pip install -q tensorflow-gpu==2.0.0-beta1

try:
  %tensorflow_version 2.x  # Colab only.
except Exception:
  pass

import tensorflow as tf
print(tf.__version__)
```

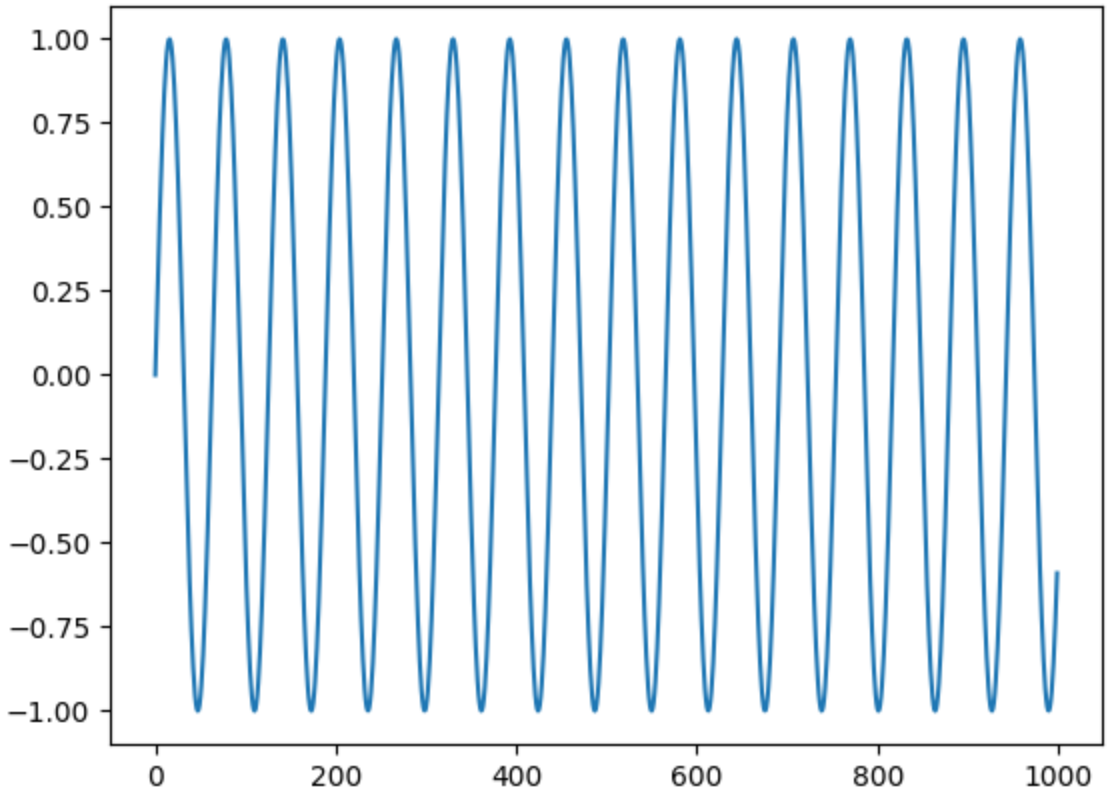
```
Colab only includes TensorFlow 2.x; %tensorflow_version has no effect.
2.12.0
```

In [2]:
```
from tensorflow.keras.layers import Input, SimpleRNN, Dense, Flatten
from tensorflow.keras.models import Model
from tensorflow.keras.optimizers import SGD, Adam

import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
```

In [3]:
```
# make the original data
series = np.sin(0.1*np.arange(1000)) #+ np.random.randn(200)*0.1

# plot it
plt.plot(series)
plt.show()
```



In [4]:
```
### build the dataset
# let's see if we can use T past values to predict the next value
T = 10
D = 1
X = []
Y = []
for t in range(len(series) - T):
  x = series[t:t+T]
  X.append(x)
  y = series[t+T]
  Y.append(y)

X = np.array(X).reshape(-1, T, 1) # Now the data should be N x T x D
Y = np.array(Y)
N = len(X)
print("X.shape", X.shape, "Y.shape", Y.shape)
```

```
X.shape (990, 10, 1) Y.shape (990,)
```

In [5]:
```
### try autoregressive RNN model
i = Input(shape=(T, 1))
x = SimpleRNN(15, activation='relu')(i)
x = Dense(1)(x)
model = Model(i, x)
model.compile(
  loss='mse',
  optimizer=Adam(learning_rate=0.001),
)

# train the RNN
r = model.fit(
  X[:-N//2], Y[:-N//2],
  epochs=80,
  validation_data=(X[-N//2:], Y[-N//2:]),
)
```

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Epoch 1/80
16/16 [==============================] - 9s 28ms/step - loss: 0.7703 - val_loss:
0.5762
Epoch 2/80
16/16 [==============================] - 0s 15ms/step - loss: 0.4788 - val_loss:
0.3944
Epoch 3/80
16/16 [==============================] - 0s 14ms/step - loss: 0.3452 - val_loss:
0.3014
Epoch 4/80
16/16 [==============================] - 0s 14ms/step - loss: 0.2650 - val_loss:
0.2356
Epoch 5/80
16/16 [==============================] - 0s 17ms/step - loss: 0.2129 - val_loss:
0.1975
Epoch 6/80
16/16 [==============================] - 0s 14ms/step - loss: 0.1806 - val_loss:
0.1679
Epoch 7/80
16/16 [==============================] - 0s 15ms/step - loss: 0.1531 - val_loss:
0.1393
Epoch 8/80
16/16 [==============================] - 0s 15ms/step - loss: 0.1229 - val_loss:
0.1054
Epoch 9/80
16/16 [==============================] - 0s 14ms/step - loss: 0.0844 - val_loss:
0.0598
Epoch 10/80
16/16 [==============================] - 0s 14ms/step - loss: 0.0393 - val_loss:
0.0204
Epoch 11/80
16/16 [==============================] - 0s 16ms/step - loss: 0.0104 - val_loss:
0.0032
Epoch 12/80
16/16 [==============================] - 0s 15ms/step - loss: 0.0023 - val_loss:
0.0017
Epoch 13/80
16/16 [==============================] - 0s 14ms/step - loss: 0.0016 - val_loss:
0.0014
Epoch 14/80
16/16 [==============================] - 0s 15ms/step - loss: 0.0013 - val_loss:
0.0011
Epoch 15/80
16/16 [==============================] - 0s 14ms/step - loss: 0.0010 - val_loss:
8.7952e-04
Epoch 16/80
16/16 [==============================] - 0s 14ms/step - loss: 8.5632e-04 - val_los
s: 7.3174e-04
Epoch 17/80
16/16 [==============================] - 0s 14ms/step - loss: 7.2301e-04 - val_los
s: 6.2362e-04
Epoch 18/80
16/16 [==============================] - 0s 14ms/step - loss: 6.3600e-04 - val_los
s: 5.4577e-04
Epoch 19/80
16/16 [==============================] - 0s 14ms/step - loss: 5.4970e-04 - val_los
```

```
s: 5.0095e-04
Epoch 20/80
16/16 [==============================] - 0s 14ms/step - loss: 4.8659e-04 - val_los
s: 4.4510e-04
Epoch 21/80
16/16 [==============================] - 0s 13ms/step - loss: 4.2977e-04 - val_los
s: 3.8617e-04
Epoch 22/80
16/16 [==============================] - 0s 14ms/step - loss: 3.8907e-04 - val_los
s: 3.3262e-04
Epoch 23/80
16/16 [==============================] - 0s 16ms/step - loss: 3.2164e-04 - val_los
s: 2.9009e-04
Epoch 24/80
16/16 [==============================] - 0s 14ms/step - loss: 2.8635e-04 - val_los
s: 2.6266e-04
Epoch 25/80
16/16 [==============================] - 0s 14ms/step - loss: 2.6053e-04 - val_los
s: 2.4432e-04
Epoch 26/80
16/16 [==============================] - 0s 14ms/step - loss: 2.3991e-04 - val_los
s: 2.2204e-04
Epoch 27/80
16/16 [==============================] - 0s 24ms/step - loss: 2.2486e-04 - val_los
s: 2.0467e-04
Epoch 28/80
16/16 [==============================] - 0s 22ms/step - loss: 2.1404e-04 - val_los
s: 2.2543e-04
Epoch 29/80
16/16 [==============================] - 0s 23ms/step - loss: 1.9902e-04 - val_los
s: 1.7953e-04
Epoch 30/80
16/16 [==============================] - 0s 24ms/step - loss: 1.7856e-04 - val_los
s: 1.6567e-04
Epoch 31/80
16/16 [==============================] - 0s 24ms/step - loss: 1.6436e-04 - val_los
s: 1.5489e-04
Epoch 32/80
16/16 [==============================] - 0s 23ms/step - loss: 1.5322e-04 - val_los
s: 1.5361e-04
Epoch 33/80
16/16 [==============================] - 0s 24ms/step - loss: 1.4708e-04 - val_los
s: 1.3745e-04
Epoch 34/80
16/16 [==============================] - 0s 16ms/step - loss: 1.3798e-04 - val_los
s: 1.2410e-04
Epoch 35/80
16/16 [==============================] - 0s 15ms/step - loss: 1.3161e-04 - val_los
s: 1.2120e-04
Epoch 36/80
16/16 [==============================] - 0s 14ms/step - loss: 1.2318e-04 - val_los
s: 1.0887e-04
Epoch 37/80
16/16 [==============================] - 0s 13ms/step - loss: 1.1032e-04 - val_los
s: 1.0264e-04
Epoch 38/80
```

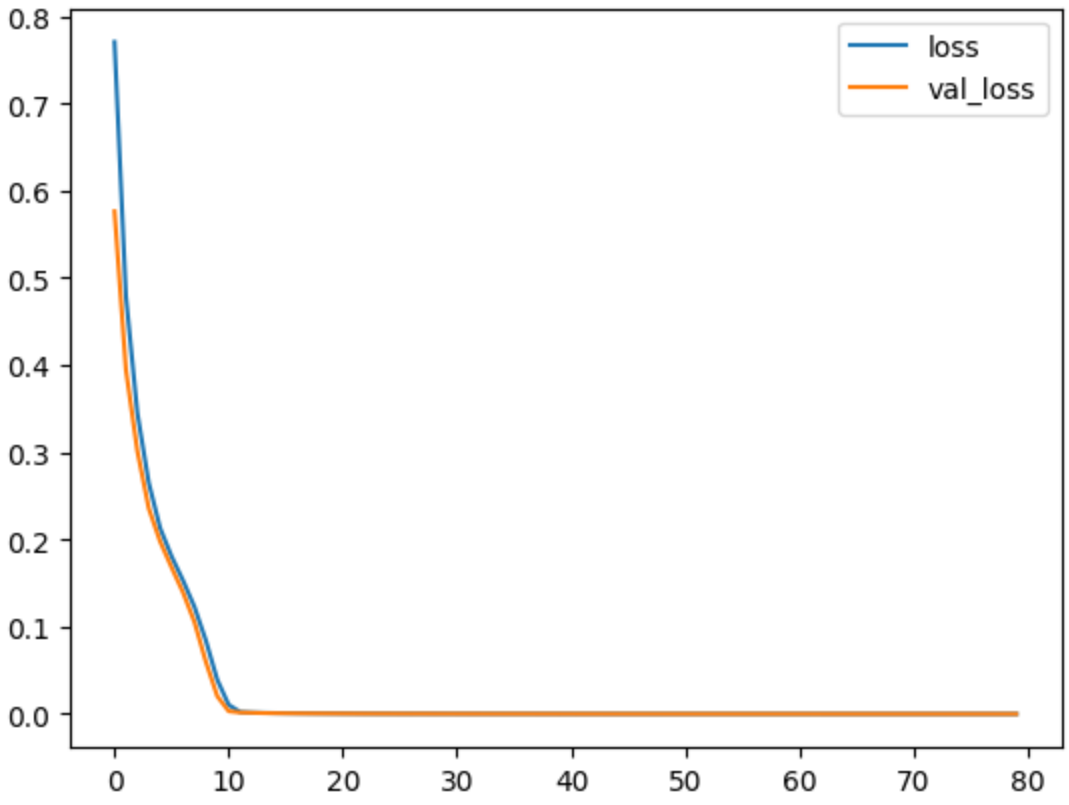
```
16/16 [==============================] - 0s 15ms/step - loss: 1.0342e-04 - val_los
s: 9.7428e-05
Epoch 39/80
16/16 [==============================] - 0s 15ms/step - loss: 1.0328e-04 - val_los
s: 8.9736e-05
Epoch 40/80
16/16 [==============================] - 0s 15ms/step - loss: 9.0687e-05 - val_los
s: 8.1909e-05
Epoch 41/80
16/16 [==============================] - 0s 16ms/step - loss: 8.4880e-05 - val_los
s: 8.4079e-05
Epoch 42/80
16/16 [==============================] - 0s 14ms/step - loss: 8.0597e-05 - val_los
s: 7.1610e-05
Epoch 43/80
16/16 [==============================] - 0s 15ms/step - loss: 7.5126e-05 - val_los
s: 6.8366e-05
Epoch 44/80
16/16 [==============================] - 0s 14ms/step - loss: 6.9401e-05 - val_los
s: 6.3489e-05
Epoch 45/80
16/16 [==============================] - 0s 15ms/step - loss: 6.5200e-05 - val_los
s: 5.8865e-05
Epoch 46/80
16/16 [==============================] - 0s 15ms/step - loss: 6.0515e-05 - val_los
s: 5.4896e-05
Epoch 47/80
16/16 [==============================] - 0s 13ms/step - loss: 5.6336e-05 - val_los
s: 5.4170e-05
Epoch 48/80
16/16 [==============================] - 0s 13ms/step - loss: 5.4883e-05 - val_los
s: 4.9505e-05
Epoch 49/80
16/16 [==============================] - 0s 15ms/step - loss: 5.2122e-05 - val_los
s: 4.7040e-05
Epoch 50/80
16/16 [==============================] - 0s 15ms/step - loss: 4.8721e-05 - val_los
s: 4.5479e-05
Epoch 51/80
16/16 [==============================] - 0s 14ms/step - loss: 4.8224e-05 - val_los
s: 4.5544e-05
Epoch 52/80
16/16 [==============================] - 0s 15ms/step - loss: 4.5515e-05 - val_los
s: 4.0861e-05
Epoch 53/80
16/16 [==============================] - 0s 14ms/step - loss: 4.1571e-05 - val_los
s: 3.9093e-05
Epoch 54/80
16/16 [==============================] - 0s 15ms/step - loss: 3.9395e-05 - val_los
s: 3.9595e-05
Epoch 55/80
16/16 [==============================] - 0s 15ms/step - loss: 3.9628e-05 - val_los
s: 3.5186e-05
Epoch 56/80
16/16 [==============================] - 0s 14ms/step - loss: 3.7402e-05 - val_los
s: 3.7017e-05
```

```
Epoch 57/80
16/16 [==============================] - 0s 14ms/step - loss: 3.6061e-05 - val_los
s: 3.2282e-05
Epoch 58/80
16/16 [==============================] - 0s 16ms/step - loss: 3.4677e-05 - val_los
s: 3.6901e-05
Epoch 59/80
16/16 [==============================] - 0s 13ms/step - loss: 3.5835e-05 - val_los
s: 3.1135e-05
Epoch 60/80
16/16 [==============================] - 0s 14ms/step - loss: 3.0202e-05 - val_los
s: 2.8814e-05
Epoch 61/80
16/16 [==============================] - 0s 15ms/step - loss: 3.2129e-05 - val_los
s: 3.1352e-05
Epoch 62/80
16/16 [==============================] - 0s 14ms/step - loss: 3.0246e-05 - val_los
s: 2.7856e-05
Epoch 63/80
16/16 [==============================] - 0s 17ms/step - loss: 2.9054e-05 - val_los
s: 2.5696e-05
Epoch 64/80
16/16 [==============================] - 0s 15ms/step - loss: 2.8576e-05 - val_los
s: 2.8779e-05
Epoch 65/80
16/16 [==============================] - 0s 16ms/step - loss: 2.5991e-05 - val_los
s: 2.3803e-05
Epoch 66/80
16/16 [==============================] - 0s 14ms/step - loss: 2.5604e-05 - val_los
s: 2.8786e-05
Epoch 67/80
16/16 [==============================] - 0s 15ms/step - loss: 2.7499e-05 - val_los
s: 2.1907e-05
Epoch 68/80
16/16 [==============================] - 0s 15ms/step - loss: 2.3186e-05 - val_los
s: 2.1056e-05
Epoch 69/80
16/16 [==============================] - 0s 13ms/step - loss: 2.1662e-05 - val_los
s: 2.0646e-05
Epoch 70/80
16/16 [==============================] - 0s 15ms/step - loss: 2.1064e-05 - val_los
s: 1.9784e-05
Epoch 71/80
16/16 [==============================] - 0s 17ms/step - loss: 2.0775e-05 - val_los
s: 2.0592e-05
Epoch 72/80
16/16 [==============================] - 0s 14ms/step - loss: 2.2474e-05 - val_los
s: 1.9223e-05
Epoch 73/80
16/16 [==============================] - 0s 14ms/step - loss: 2.1126e-05 - val_los
s: 2.3207e-05
Epoch 74/80
16/16 [==============================] - 0s 15ms/step - loss: 2.1338e-05 - val_los
s: 1.8693e-05
Epoch 75/80
16/16 [==============================] - 0s 16ms/step - loss: 2.0339e-05 - val_los
```

```
s: 1.8698e-05
Epoch 76/80
16/16 [==============================] - 0s 25ms/step - loss: 1.8349e-05 - val_los
s: 1.7274e-05
Epoch 77/80
16/16 [==============================] - 0s 28ms/step - loss: 1.7765e-05 - val_los
s: 1.6030e-05
Epoch 78/80
16/16 [==============================] - 0s 23ms/step - loss: 1.5993e-05 - val_los
s: 1.6055e-05
Epoch 79/80
16/16 [==============================] - 0s 22ms/step - loss: 1.6160e-05 - val_los
s: 1.6278e-05
Epoch 80/80
16/16 [==============================] - 0s 23ms/step - loss: 1.6399e-05 - val_los
s: 1.6777e-05
```

In [6]:
```
# Plot loss per iteration
import matplotlib.pyplot as plt
plt.plot(r.history['loss'], label='loss')
plt.plot(r.history['val_loss'], label='val_loss')
plt.legend()
```

Out[6]:
```
<matplotlib.legend.Legend at 0x7f49315d81c0>
```



In [7]:
```
# "Wrong" forecast using true targets

validation_target = Y[-N//2:]
validation_predictions = []

# index of first validation input
```

```
i = -N//2

while len(validation_predictions) < len(validation_target):
  p = model.predict(X[i].reshape(1, -1, 1))[0,0] # 1x1 array -> scalar
  i += 1

  # update the predictions list
  validation_predictions.append(p)
```

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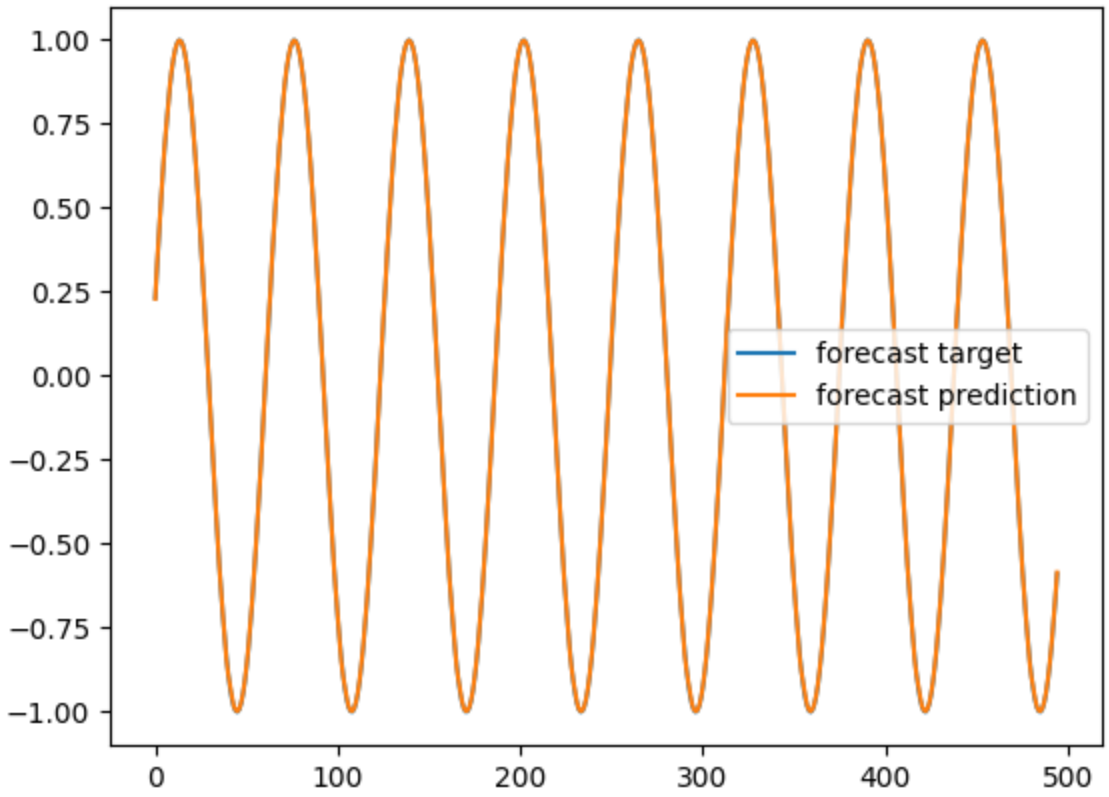
In [8]:
```
plt.plot(validation_target, label='forecast target')
plt.plot(validation_predictions, label='forecast prediction')
plt.legend()
```

Out[8]:
```
<matplotlib.legend.Legend at 0x7f48a1e1e6e0>
```



In [9]:
```
# Forecast future values (use only self-predictions for making future predictions)

validation_target = Y[-N//2:]
validation_predictions = []

# first validation input
last_x = X[-N//2] # 1-D array of length T

while len(validation_predictions) < len(validation_target):
  p = model.predict(last_x.reshape(1, -1, 1))[0,0] # 1x1 array -> scalar

  # update the predictions list
  validation_predictions.append(p)

  # make the new input
  last_x = np.roll(last_x, -1)
  last_x[-1] = p
```

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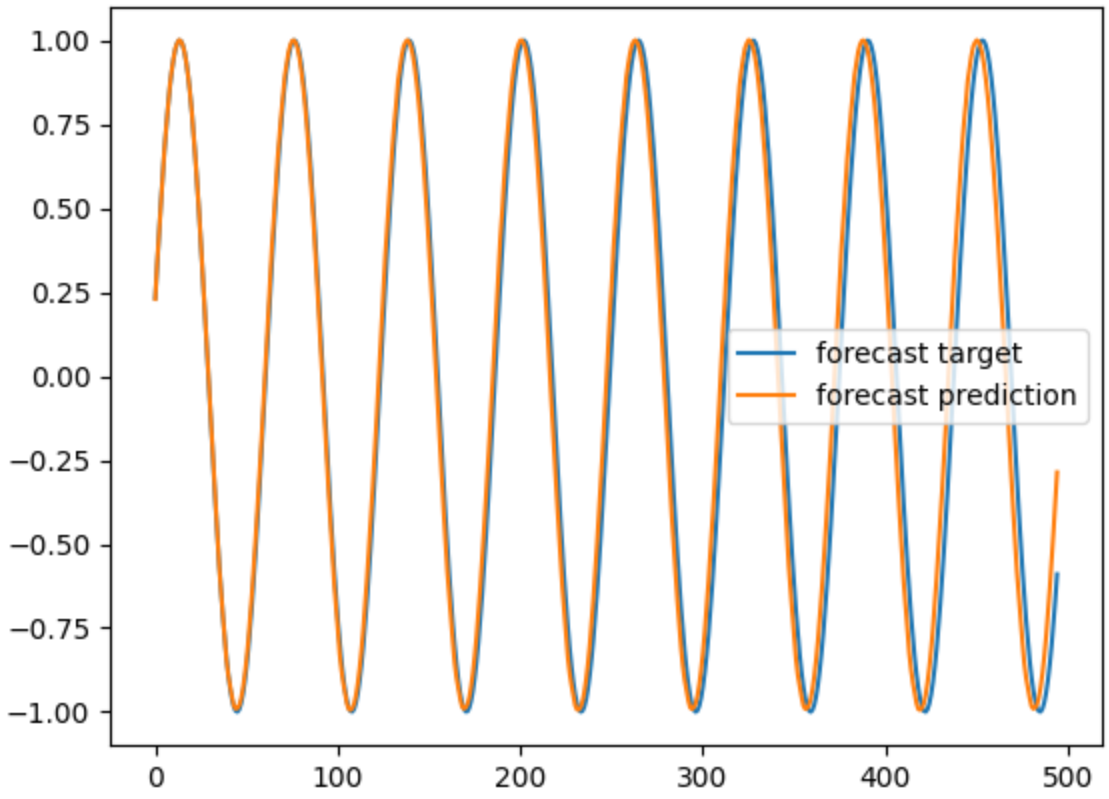
In [10]:
```
plt.plot(validation_target, label='forecast target')
plt.plot(validation_predictions, label='forecast prediction')
plt.legend()
```

Out[10]:
```
<matplotlib.legend.Legend at 0x7f48a01fa470>
```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forecast target
forecast prediction