In [1]:
```python
import os
import numpy as np
import torch as T
import torch.nn as nn
import torch.optim as optim
from torch.distributions.normal import Normal
import matplotlib.pyplot as plt
import gym
```

```
D:\miniconda3\envs\cmpe260\lib\site-packages\tqdm\auto.py:22: TqdmWarning: IProgress not foun
d. Please update jupyter and ipywidgets. See https://ipywidgets.readthedocs.io/en/stable/user
_install.html
  from .autonotebook import tqdm as notebook_tqdm
```

In [2]:
```python
import a3_gym_env
gym.make('Pendulum-v260')
```

Out[2]:
```
<OrderEnforcing<PassiveEnvChecker<CustomPendulumEnv<Pendulum-v260>>>>
```

In [3]:
```python
class ReplayBuffer:
    def __init__(self):
        self.states = []
        self.probs = []
        self.vals = []
        self.actions = []
        self.rewards = []
        self.dones = []

    def store_memory(self, state, action, probs, vals, reward, done):
        self.states.append(state)
        self.actions.append(action)
        self.probs.append(probs)
        self.vals.append(vals)
        self.rewards.append(reward)
        self.dones.append(done)
```

In [4]:
```python
class ActorNetwork(nn.Module):
    def __init__(self, input_dims, output_dims, alpha,
                 hidden_layers = 2, hidden_dims=8, N=1):
        super().__init__()
        # actor network to estimate mean of the gaussian distribution
        self.actor = nn.Sequential()
        self.actor.append(nn.Linear(*input_dims, hidden_dims))
        for i in range(hidden_layers):
            self.actor.append(nn.Linear(hidden_dims, hidden_dims))
            self.actor.append(nn.ReLU())
        self.actor.append(nn.Linear(hidden_dims, output_dims))
        # use constant standard deviation
        log_std = -0.9 * np.ones(output_dims, dtype=np.float32)
        self.log_std = T.nn.Parameter(T.as_tensor(log_std))

        self.optimizer = optim.Adam(self.parameters(), lr=alpha/N, eps=1e-05)
#          self.scheduler = optim.lr_scheduler.ReduceLROnPlateau(self.optimizer)
        self.device = T.device('cuda:0' if T.cuda.is_available() else 'cpu')
        self.to(self.device)

    def forward(self, state):
        m = self.actor(state)
        # return normal distribution
        dist = Normal(m, T.exp(self.log_std))
        return dist
```

In [5]:
```
class CriticNetwork(nn.Module):
    def __init__(self, input_dims, alpha, hidden_layers = 2, hidden_dims=8, N=1):
        super().__init__()
        # crtic network for estimating value
        self.critic = nn.Sequential()
        self.critic.append(nn.Linear(*input_dims, hidden_dims))
        for i in range(hidden_layers):
            self.critic.append(nn.Linear(hidden_dims, hidden_dims))
            self.critic.append(nn.ReLU())
            self.critic.append(nn.Linear(hidden_dims, hidden_dims))
            self.critic.append(nn.ReLU())
            self.critic.append(nn.Linear(hidden_dims, hidden_dims))
            self.critic.append(nn.ReLU())
        self.critic.append(nn.Linear(hidden_dims, 1))

        self.optimizer = optim.Adam(self.parameters(), lr=alpha/N, eps=1e-05)
#         self.scheduler = optim.lr_scheduler.ReduceLROnPlateau(self.optimizer)
        self.device = T.device('cuda:0' if T.cuda.is_available() else 'cpu')
        self.to(self.device)

    def forward(self, state):
        # return value
        value = self.critic(state)
        return value
```

In [6]:
```
def choose_action_value(observation, actor, critics):
        # convert state to tensor
        state = T.tensor([observation], dtype=T.float).to(actor.device)
        # get gaussian distribution for state
        dist = actor(state)
        # get value for current state
        value = T.tensor([critic(state) for critic in critics]).mean()
        # sample action
        action = dist.sample()

        # get log prob for sampled action (to be used for ratio)
        probs = T.squeeze(dist.log_prob(action)).item()
        action = T.squeeze(action).item()
        value = T.squeeze(value).item()
        # return action, log prob for sampled action and value for current state
        return action, probs, value
```

In [7]:
```python
def get_advantages(gamma, lmbda, values, dones, rewards,
                   next_value, next_done, use_gae):
    num_steps = len(rewards)
    if use_gae:
        advantages = np.zeros_like(rewards)
        last_gae_lam = 0
        for t in reversed(range(num_steps)):
            if t == num_steps - 1:
                next_non_terminal = 1.0 - next_done
                next_values = next_value
            else:
                next_non_terminal = 1.0 - dones[t + 1]
                next_values = values[t + 1]
            delta = rewards[t] + gamma * next_values * next_non_terminal - values[t]
            advantages[t] = last_gae_lam = delta + gamma * lmbda * next_non_terminal * last_ga

        returns = advantages + values
    else:
        returns = np.zeros_like(rewards)
        for t in reversed(range(num_steps)):
            if t == num_steps - 1:
                next_non_terminal = 1.0 - next_done
                next_return = next_value
            else:
                next_non_terminal = 1.0 - dones[t + 1]
                next_return = returns[t + 1]
            returns[t] = rewards[t] + gamma * next_non_terminal * next_return
        advantages = returns - values
    return returns, advantages
```

In [8]:
```python
def combine_trajectories(trajectories):
    c_states = []
    c_actions = []
    c_rewards = []
    c_logprobs = []
    c_values = []
    c_dones = []
    c_returns = []
    c_advantages = []
    for k, v in trajectories.items():
        buf, ret, adv = v
        c_states.extend(buf.states)
        c_actions.extend(buf.actions)
        c_rewards.extend(buf.rewards)
        c_logprobs.extend(buf.probs)
        c_values.extend(buf.vals)
        c_dones.extend(buf.dones)
        c_returns.extend(ret)
        c_advantages.extend(adv)
    return {
        'states': c_states,
        'actions': c_actions,
        'rewards': c_rewards,
        'logprobs': c_logprobs,
        'values': c_values,
        'dones': c_dones,
        'returns': c_returns,
        'advantages': c_advantages,
    }
```

In [9]:

```
def ppo(N = 1, M = 50, max_trajectory_len = 200, batch_size = 25,
        alpha = 0.0001, hidden_layers = 2, hidden_dims = 8, gamma = 0.99,
        lmbda = 0.95, clip_value = 0.2, use_gae=True, use_clip=True, n_critic=1):
    # N = 1 # number of times to collect new trajectories and update actor
    # M = 50 # num of trajectories
    # max_trajectory_len = 200 # trajectory length
    # batch_size = 25 # size for minibatch
    # n_epochs = 30 # number of epochs to optimize loss
    # alpha = 0.00005
    # hidden_layers = 3
    # hidden_dims = 10
    # gamma = 0.8
    # lmbda = 0.95
    # clip_value = 0.2
    # use_gae = True
    # use_clip = True

    env = gym.make('Pendulum-v260')
    input_dim = env.observation_space.shape
    actor = ActorNetwork(input_dims=input_dim, output_dims=1, alpha=alpha,
                         hidden_layers=hidden_layers, hidden_dims=hidden_dims)
    critics = [CriticNetwork(input_dims=input_dim, alpha=alpha,
                             hidden_layers=hidden_layers,
                             hidden_dims=hidden_dims) for _ in range(n_critic)]
    trajectories = {}
    total_loss_list = []
    loss_list = []
    reward_list = []
    observation_list = []
    for n in range(N):
        # collect M trajectories, their returns, and activations
        for i in range(M):
            curr_trajectory = ReplayBuffer()
            observation = env.reset()
            done = False
            steps = 0
            while steps < max_trajectory_len:
                action, prob, val = choose_action_value(
                    observation, actor, critics)
                next_observation, reward, done, info = env.step([action])
                steps +=1
                curr_trajectory.store_memory(
                    observation, action, prob, val, reward, done)
                observation = next_observation
                if done:
                    break
            # get GAE advantage
            # get value of next_observation
            next_value = T.tensor([critic(T.tensor(observation).to(actor.device)) for critic i
            # calculate return and advantage
            returns, advantages = get_advantages(
                gamma, lmbda, curr_trajectory.vals, curr_trajectory.dones,
                curr_trajectory.rewards, next_value, done, use_gae)
            trajectories[i] = (curr_trajectory, returns, advantages)

        # combine_trajectories
        c_trajectories = combine_trajectories(trajectories)
        total_steps_taken = len(c_trajectories['states'])
        indicies = np.arange(total_steps_taken)
        np.random.shuffle(indicies)

        # optimize loss
        for epoch in range(n_epochs):
            # get batches
            for start in range(0, total_steps_taken, batch_size):
                end = start + batch_size
```

```
                end = start + batch_size
                # batch indicies
                b_indicies = indicies[start:end]

                states = T.tensor(
                    np.array(c_trajectories['states'])[b_indicies],
                    dtype=T.float).to(actor.device)
                new_values = T.stack([critic(states) for critic in critics]).mean(axis=0)
                distr = actor(states)

                old_log_prob = T.tensor(
                    np.array(c_trajectories['logprobs'])[b_indicies]).to(actor.device)
                actions = T.tensor(
                    np.array(c_trajectories['actions'])[b_indicies],
                    dtype=T.float).to(actor.device)
                new_log_prob = distr.log_prob(actions)

                # Probability ratio
                log_ratio = new_log_prob - old_log_prob
                ratio = log_ratio.exp()

                b_returns = T.tensor(
                    np.array(c_trajectories['returns'])[b_indicies]).to(actor.device)
                b_advantages = T.tensor(
                    np.array(c_trajectories['advantages'])[b_indicies]).to(actor.device)
#                 b_advantages = (b_advantages-b_advantages.mean())/(b_advantages.std()+1e-8)
                # Clipping
                weighted_probs = b_advantages * ratio
                if use_clip:
                    weighted_clipped_probs = T.clamp(ratio, 1-clip_value,
                            1+clip_value)*b_advantages
                    actor_loss = -T.min(
                        weighted_probs, weighted_clipped_probs).mean()
                else:
                    weighted_probs = b_advantages * ratio
                    actor_loss = -(weighted_probs).mean()
                critic_loss = (b_returns-new_values)**2
                critic_loss = critic_loss.mean()

                total_loss = actor_loss + 0.5*critic_loss
                print("n: {}, epoch: {}, minibatch no.: {},".format(
                    n, epoch, start//batch_size))
                print("total_loss: {}, actor_loss: {}, critic_loss: {}".format(
                    total_loss, actor_loss, critic_loss))

                total_loss_list.append(total_loss)
                actor.optimizer.zero_grad()
                for critic in critics:
                    critic.optimizer.zero_grad()
                total_loss.backward()
                actor.optimizer.step()
                for critic in critics:
                    critic.optimizer.step()
#             actor.scheduler.step(actor_loss)
#             critic.scheduler.step(critic_loss)

        # get a single trajectory from actor for plotting
        loss_list.append(total_loss)
        reward_list.append(b_returns.mean())

        observation = env.reset()
        done = False
        steps = 0
        while steps < 200:
            action, prob, val = choose_action_value(
                observation, actor, critics)
            next_observation, reward, done, info = env.step([action])
```

```
            next_observation, reward, done, info = env.step([action])
            observation_list.append(observation)
            observation = next_observation
            steps += 1
            if done:
                break

    return total_loss_list, observation_list, loss_list, reward_list
```

Clipped and GAE

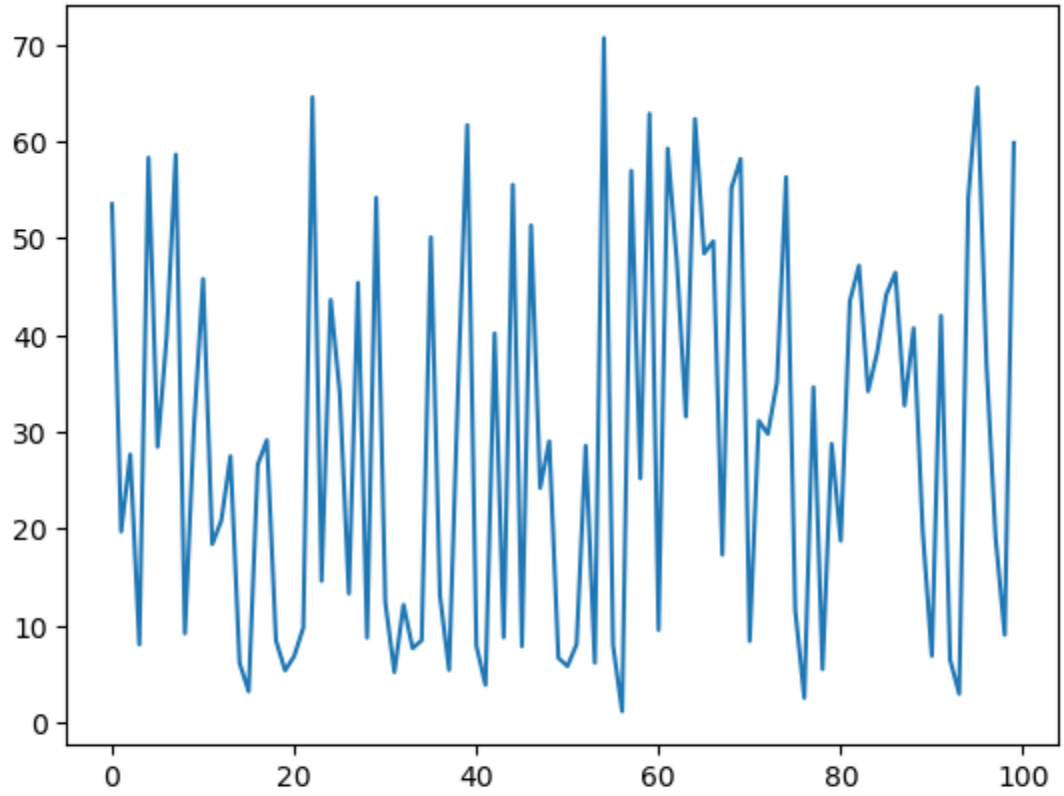
In [10]:
```
N = 100 # number of times to collect new trajectories and update actor
M = 1 # num of trajectories
max_trajectory_len = 200 # trajectory length
batch_size = 25 # size for minibatch
n_epochs = 30 # number of epochs to optimize loss
alpha = 0.0001
hidden_layers = 2
hidden_dims = 64
gamma = 0.7
lmbda = 0.9
clip_value = 0.1
use_gae = True
use_clip = True
n_critic = 5

total_losses, observations, loss_list, reward_list = ppo(
    N, M, max_trajectory_len, batch_size, alpha, hidden_layers, hidden_dims,
    gamma, lmbda, clip_value, use_gae, use_clip, n_critic)
```

```
D:\miniconda3\envs\cmpe260\lib\site-packages\gym\utils\passive_env_checker.py:195: UserWarning: WARN: The result returned by `env.reset()` was not a tuple of the form `(obs, info)`, where `obs` is a observation and `info` is a dictionary containing additional information. Actual type: `<class 'numpy.ndarray'>`
  logger.warn(
C:\Users\kj\AppData\Local\Temp\ipykernel_14260\3273781350.py:3: UserWarning: Creating a tensor from a list of numpy.ndarrays is extremely slow. Please consider converting the list to a single numpy.ndarray with numpy.array() before converting to a tensor. (Triggered internally at C:\cb\pytorch_1000000000000\work\torch\csrc\utils\tensor_new.cpp:233.)
  state = T.tensor([observation], dtype=T.float).to(actor.device)
D:\miniconda3\envs\cmpe260\lib\site-packages\gym\utils\passive_env_checker.py:219: DeprecationWarning: WARN: Core environment is written in old step API which returns one bool instead of two. It is recommended to rewrite the environment with new step API.
  logger.deprecation(
```

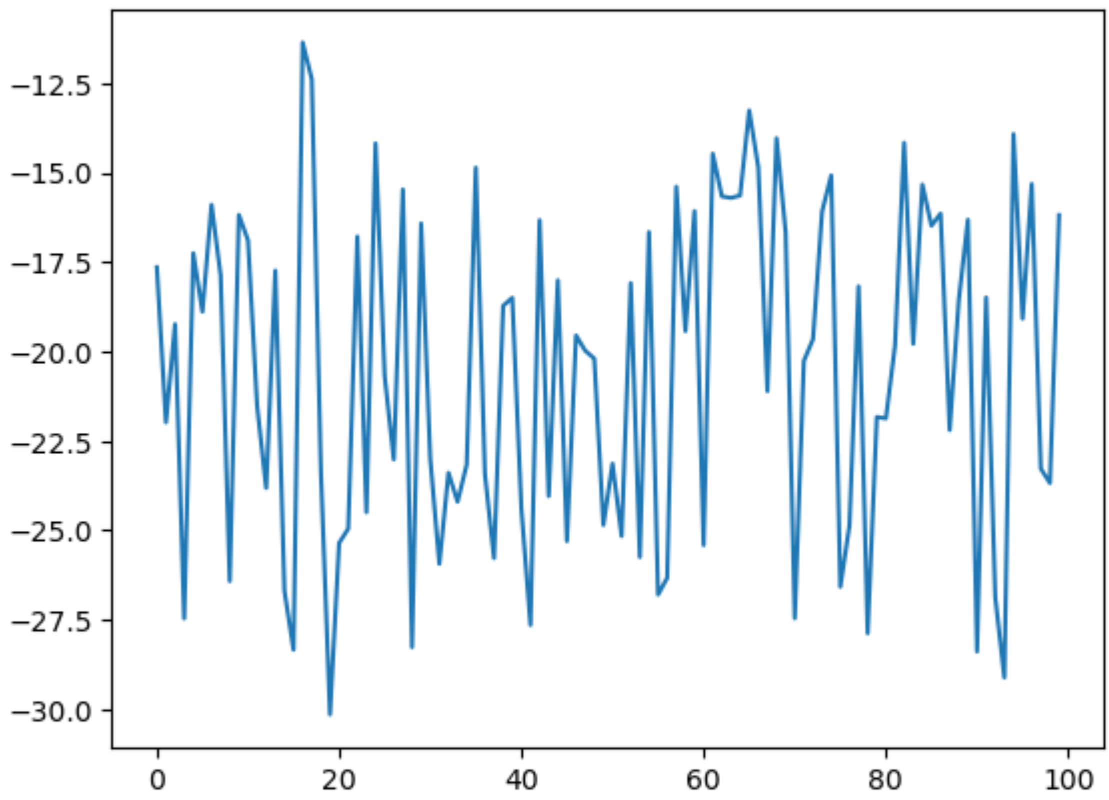
In [11]:
```
tmp = [x for x in range(100)]
```

In [12]:
```
plt.plot(tmp, np.array([l.cpu().detach() for l in loss_list]))
```

Out[12]:
```
[<matplotlib.lines.Line2D at 0x18ac4d39330>]
```




```
In [13]: plt.plot(tmp, np.array([l.cpu().detach() for l in reward_list]))

Out[13]: [<matplotlib.lines.Line2D at 0x18ad200d990>]
```

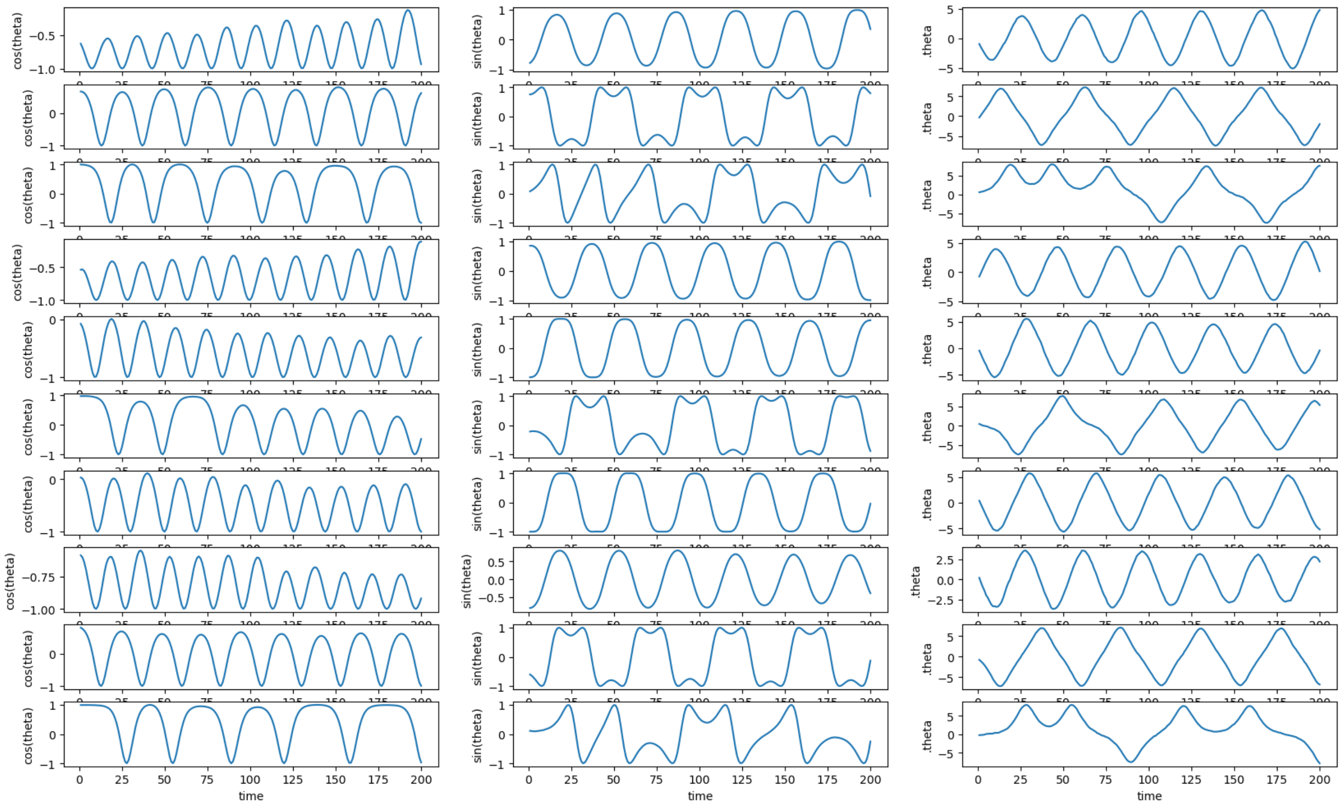



```
In [14]: o = []
         for i in range(N):
             o.append(observations[200*(i+1)-200:200*(i+1)])

In [15]: o_old = o.copy()
         o = [j for i, j in enumerate(o) if i%10==0]

In [16]: o = o_old[-10:]

In [17]: x_ = [i+1 for i in range(200)]
```

In [18]:
```
np.array(o).shape
```

Out[18]: (10, 200, 3)

In [19]:
```
N = 10
plt.figure(1, figsize=(20, 12))
for i in range(N):
    obs = o[i]
    # print(obs)
    theta_ = []
    x_list = []
    y_list = []
    for x,y,v in obs:
        # print(x, y)
        theta_.append(v)
        x_list.append(x)
        y_list.append(y)
    plt.subplot(N, 3, 3*i+1)
    plt.plot(x_, x_list)
    plt.xlabel('time')
    plt.ylabel('cos(theta)')
    plt.subplot(N, 3, 3*i+2)
    plt.plot(x_, y_list)
    plt.xlabel('time')
    plt.ylabel('sin(theta)')
    plt.subplot(N, 3, 3*i+3)
    plt.plot(x_, theta_)
    plt.xlabel('time')
    plt.ylabel('.theta')
```

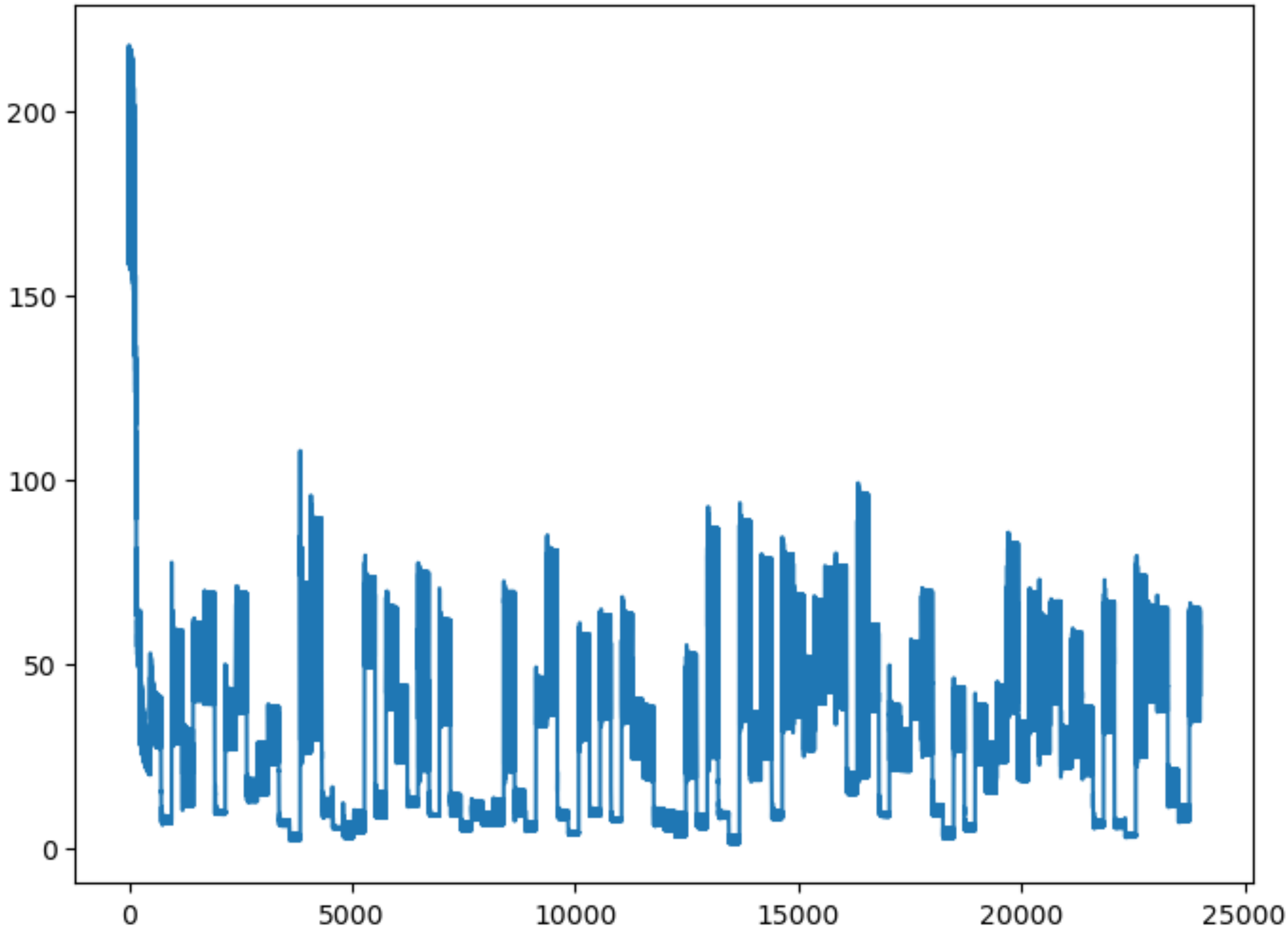


In [20]:
```
len(total_losses)
```

Out[20]: 24000

In [21]:
```
x = np.arange(len(total_losses))
y = [float(x) for x in total_losses]
plt.figure(figsize=(8, 6))
plt.plot(x, y)
```

Out[21]: [<matplotlib.lines.Line2D at 0x18bcdff1ba0>]



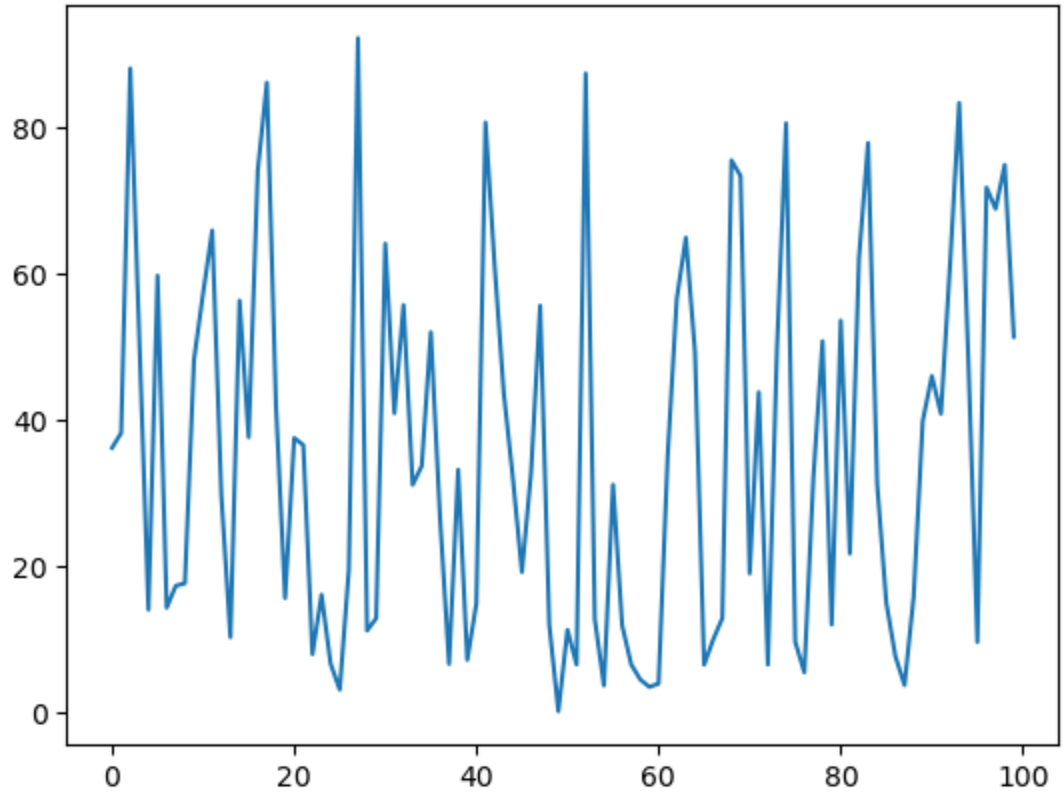
Clipped and No GAE

In [22]:
```
N = 100 # number of times to collect new trajectories and update actor
M = 1 # num of trajectories
max_trajectory_len = 200 # trajectory length
batch_size = 25 # size for minibatch
n_epochs = 30 # number of epochs to optimize loss
alpha = 0.0001
hidden_layers = 2
hidden_dims = 64
gamma = 0.7
lmbda = 0.9
clip_value = 0.1
use_gae = False
use_clip = True
n_critic = 5

total_losses, observations, loss_list, reward_list = ppo(
    N, M, max_trajectory_len, batch_size, alpha, hidden_layers, hidden_dims,
    gamma, lmbda, clip_value, use_gae, use_clip, n_critic)
```

In [23]:
```
tmp = [x for x in range(100)]
```

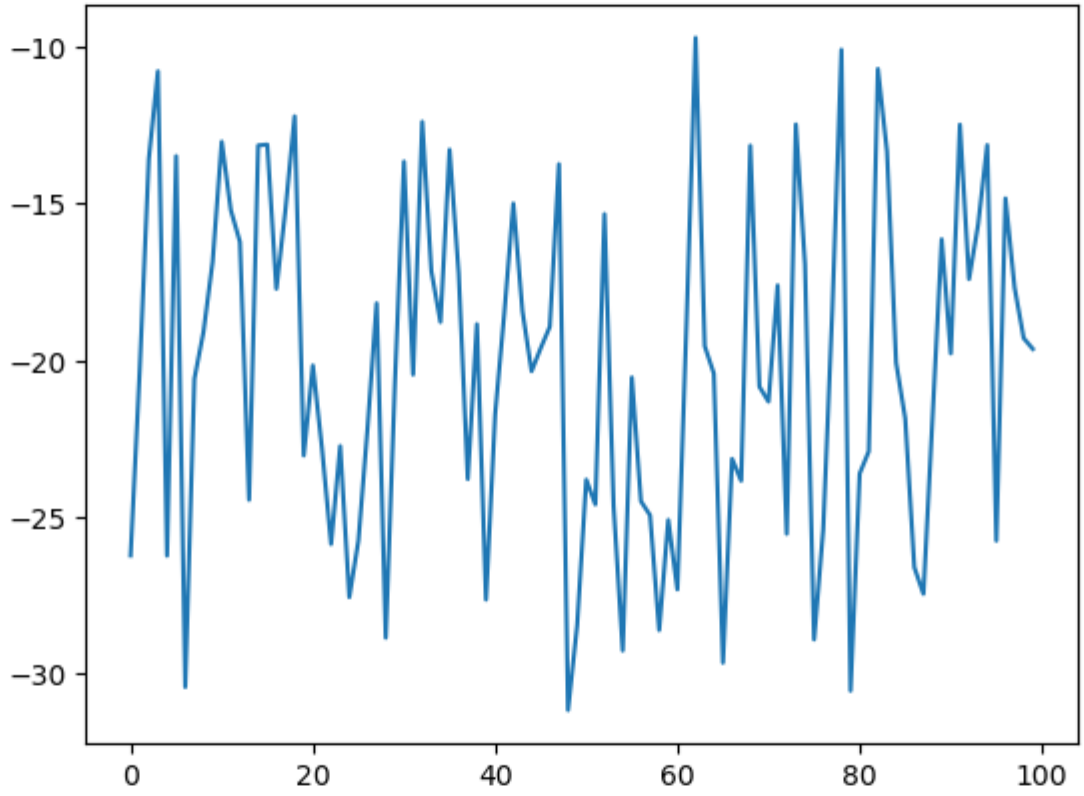
In [24]:
```
plt.plot(tmp, np.array([l.cpu().detach() for l in loss_list]))
```

Out[24]: `[<matplotlib.lines.Line2D at 0x18bcdfbc7f0>]`



In [25]:
```
plt.plot(tmp, np.array([l.cpu().detach() for l in reward_list]))
```

Out[25]:
```
[<matplotlib.lines.Line2D at 0x18bcdf08f40>]
```



In [26]:
```
o = []
for i in range(N):
    o.append(observations[200*(i+1)-200:200*(i+1)])
```

In [27]:
```
o_old = o.copy()
o = [j for i, j in enumerate(o) if i%10==0]
```

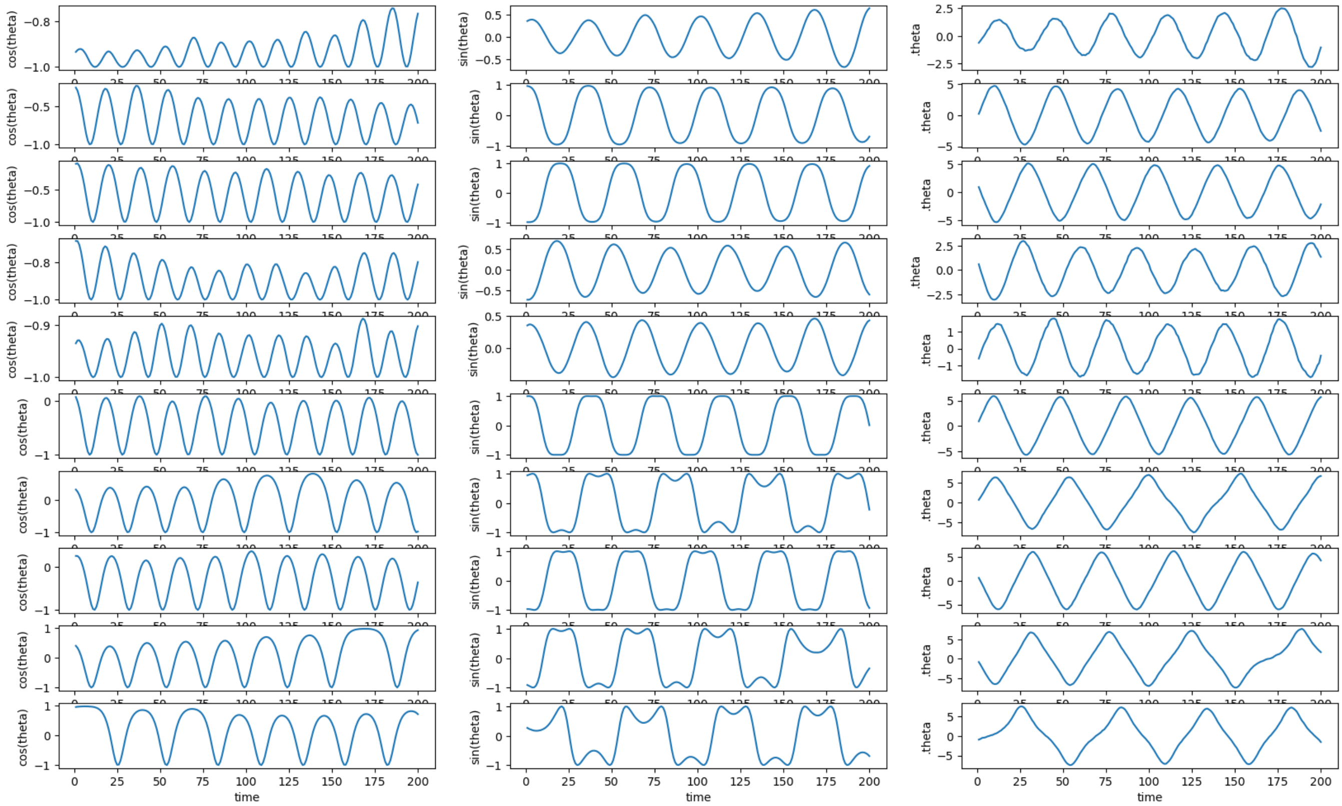
In [28]:
```
o = o_old[-10:]
```

In [29]:
```
x_ = [i+1 for i in range(200)]
```

In [30]:
```
np.array(o).shape
```

Out[30]:
```
(10, 200, 3)
```

In [31]:
```
N = 10
plt.figure(1, figsize=(20, 12))
for i in range(N):
    obs = o[i]
    # print(obs)
    theta_ = []
    x_list = []
    y_list = []
    for x,y,v in obs:
        # print(x, y)
        theta_.append(v)
        x_list.append(x)
        y_list.append(y)
    plt.subplot(N, 3, 3*i+1)
    plt.plot(x_, x_list)
    plt.xlabel('time')
    plt.ylabel('cos(theta)')
    plt.subplot(N, 3, 3*i+2)
    plt.plot(x_, y_list)
    plt.xlabel('time')
    plt.ylabel('sin(theta)')
    plt.subplot(N, 3, 3*i+3)
    plt.plot(x_, theta_)
    plt.xlabel('time')
    plt.ylabel('.theta')
```

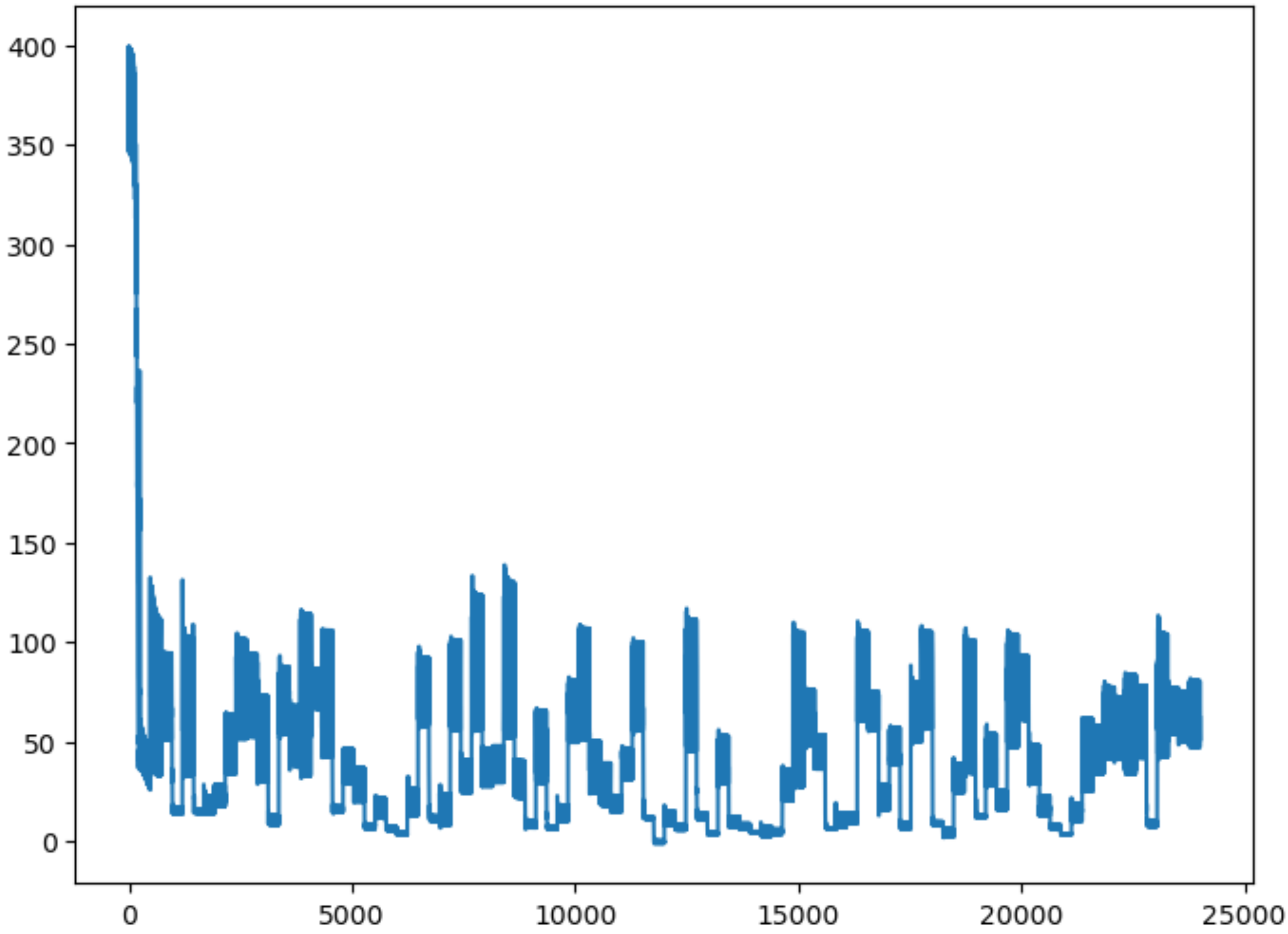


In [32]:
```
len(total_losses)
```

Out[32]:
```
24000
```

In [33]:
```
x = np.arange(len(total_losses))
y = [float(x) for x in total_losses]
plt.figure(figsize=(8, 6))
plt.plot(x, y)
```

Out[33]: [<matplotlib.lines.Line2D at 0x18bcd45ac20>]



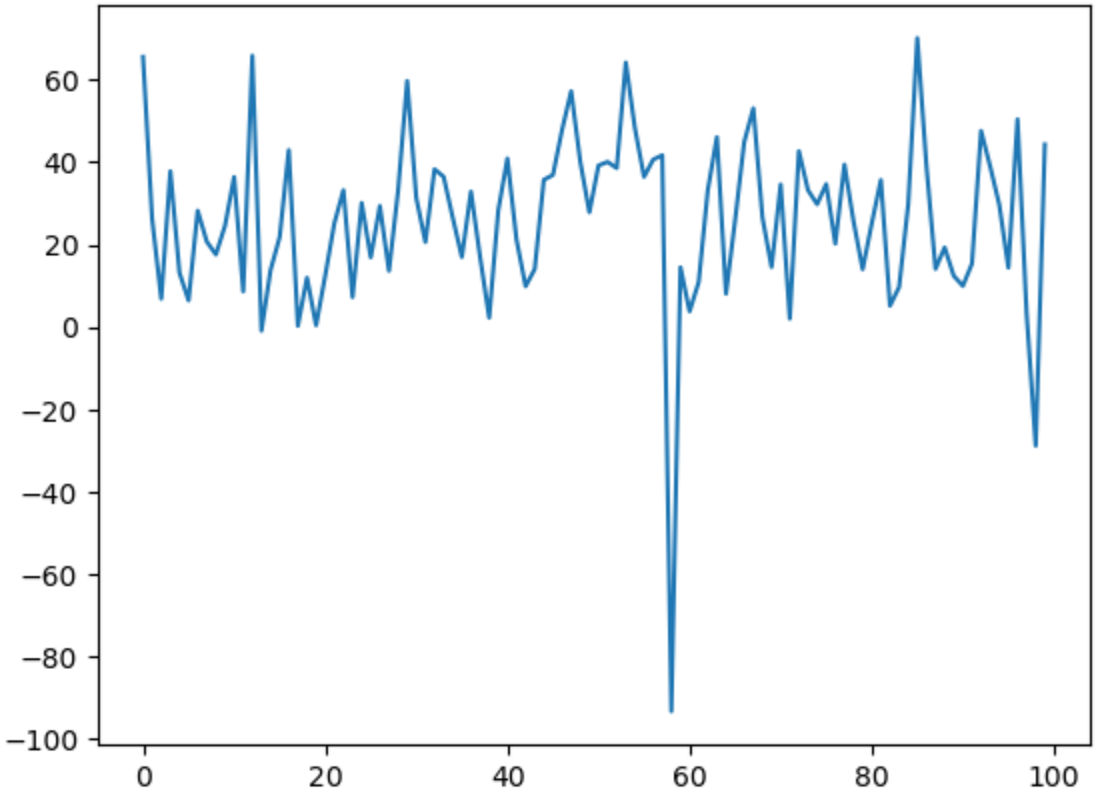
No Clipping and GAE

In [34]:
```
N = 100 # number of times to collect new trajectories and update actor
M = 1 # num of trajectories
max_trajectory_len = 200 # trajectory length
batch_size = 25 # size for minibatch
n_epochs = 30 # number of epochs to optimize loss
alpha = 0.0001
hidden_layers = 2
hidden_dims = 64
gamma = 0.7
lmbda = 0.9
clip_value = 0.1
use_gae = True
use_clip = False
n_critic = 5

total_losses, observations, loss_list, reward_list = ppo(
    N, M, max_trajectory_len, batch_size, alpha, hidden_layers, hidden_dims,
    gamma, lmbda, clip_value, use_gae, use_clip, n_critic)
```

In [35]:
```
tmp = [x for x in range(100)]
```

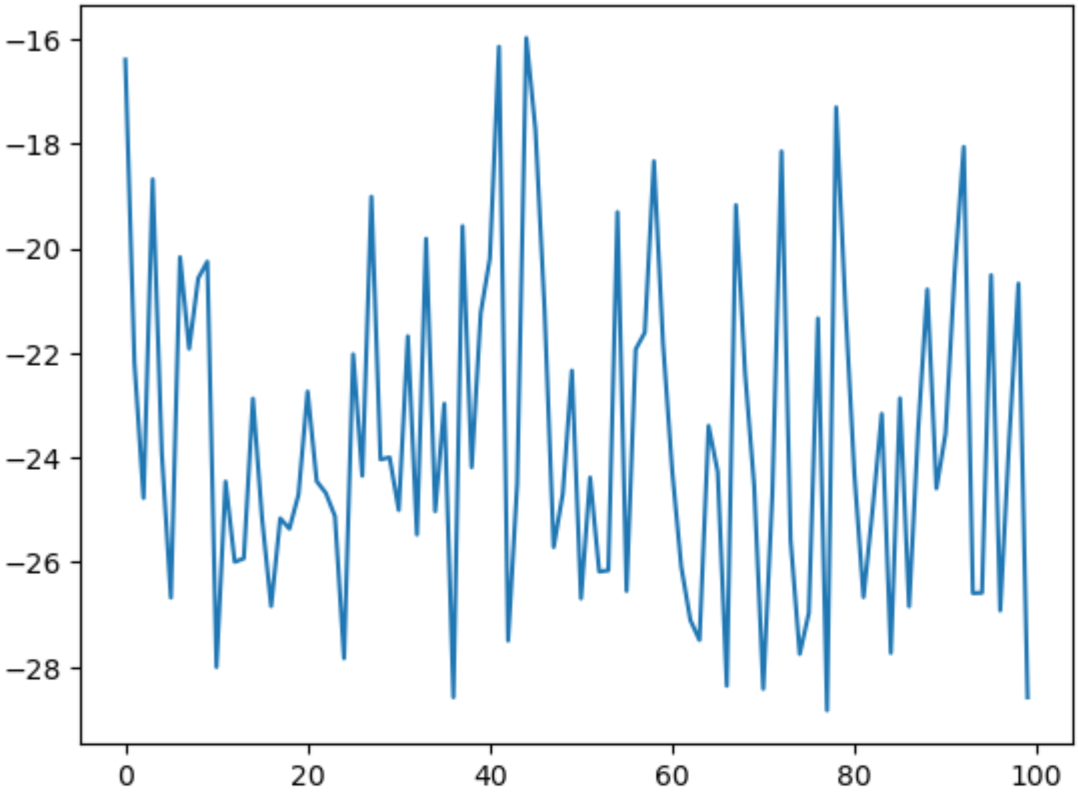
In [36]:
```
plt.plot(tmp, np.array([l.cpu().detach() for l in loss_list]))
```

Out[36]: [<matplotlib.lines.Line2D at 0x18b160d2a10>]



In [37]:
```
plt.plot(tmp, np.array([l.cpu().detach() for l in reward_list]))
```

Out[37]:
```
[<matplotlib.lines.Line2D at 0x18bcd3c82b0>]
```



In [38]:
```
o = []
for i in range(N):
    o.append(observations[200*(i+1)-200:200*(i+1)])
```

In [39]:
```
o_old = o.copy()
o = [j for i, j in enumerate(o) if i%10==0]
```

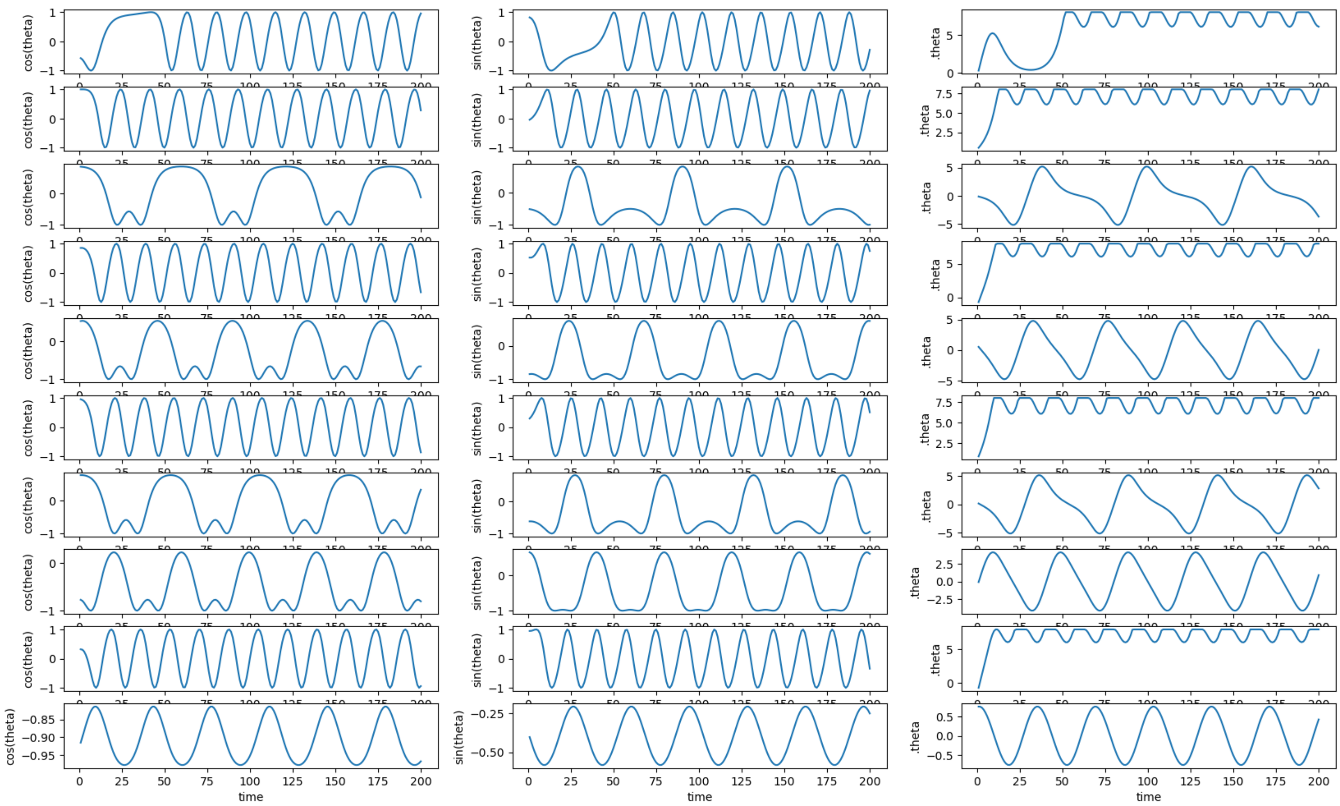
In [40]:
```
o = o_old[-10:]
```

In [41]:
```
x_ = [i+1 for i in range(200)]
```

In [42]:
```python
np.array(o).shape
```

Out[42]: (10, 200, 3)

In [43]:
```python
N = 10
plt.figure(1, figsize=(20, 12))
for i in range(N):
    obs = o[i]
    # print(obs)
    theta_ = []
    x_list = []
    y_list = []
    for x,y,v in obs:
        # print(x, y)
        theta_.append(v)
        x_list.append(x)
        y_list.append(y)
    plt.subplot(N, 3, 3*i+1)
    plt.plot(x_, x_list)
    plt.xlabel('time')
    plt.ylabel('cos(theta)')
    plt.subplot(N, 3, 3*i+2)
    plt.plot(x_, y_list)
    plt.xlabel('time')
    plt.ylabel('sin(theta)')
    plt.subplot(N, 3, 3*i+3)
    plt.plot(x_, theta_)
    plt.xlabel('time')
    plt.ylabel('.theta')
```

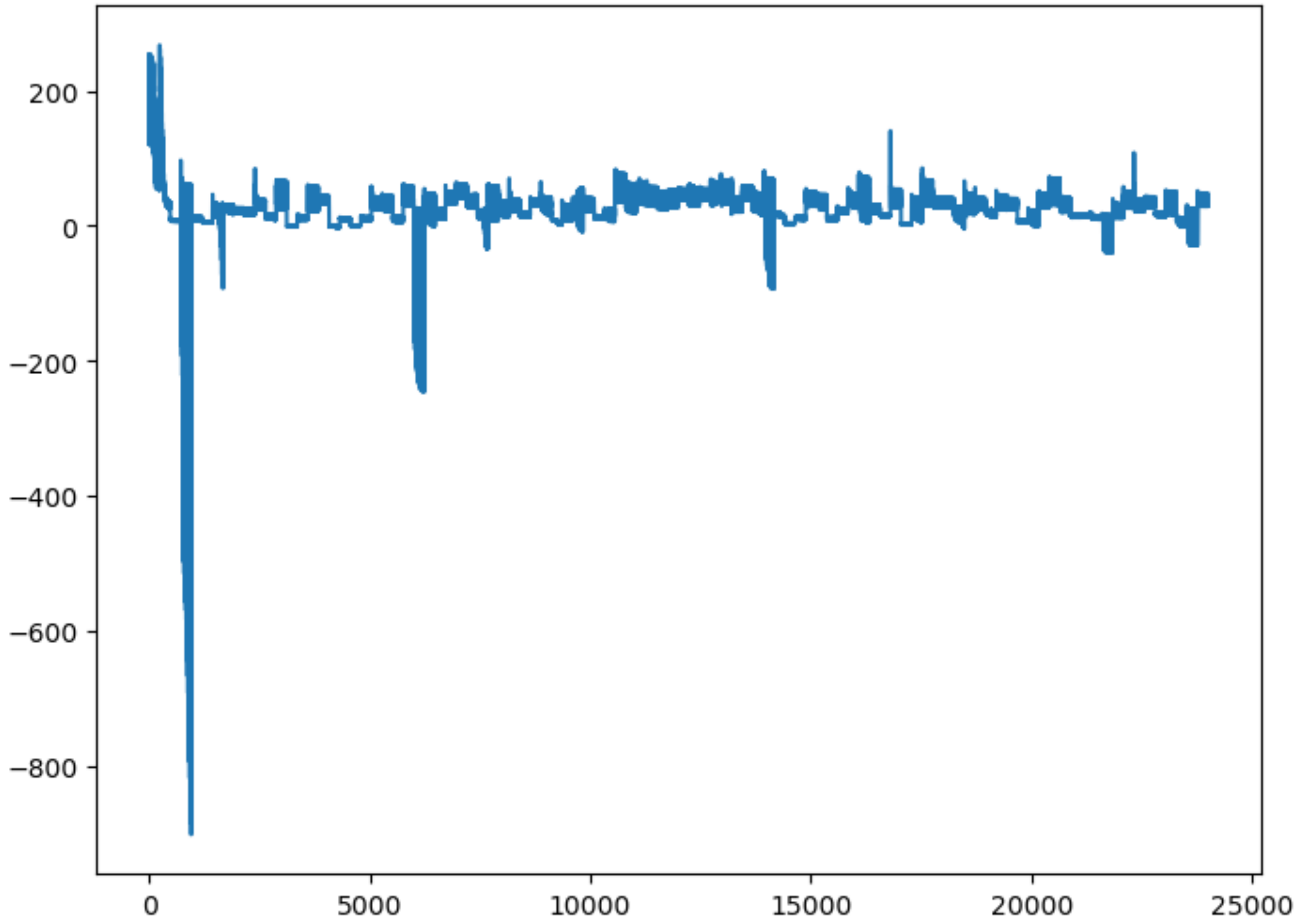


In [44]:
```python
len(total_losses)
```

Out[44]: 24000

In [45]:
```python
x = np.arange(len(total_losses))
y = [float(x) for x in total_losses]
plt.figure(figsize=(8, 6))
plt.plot(x, y)
```

Out[45]: [<matplotlib.lines.Line2D at 0x18bce0a5fc0>]



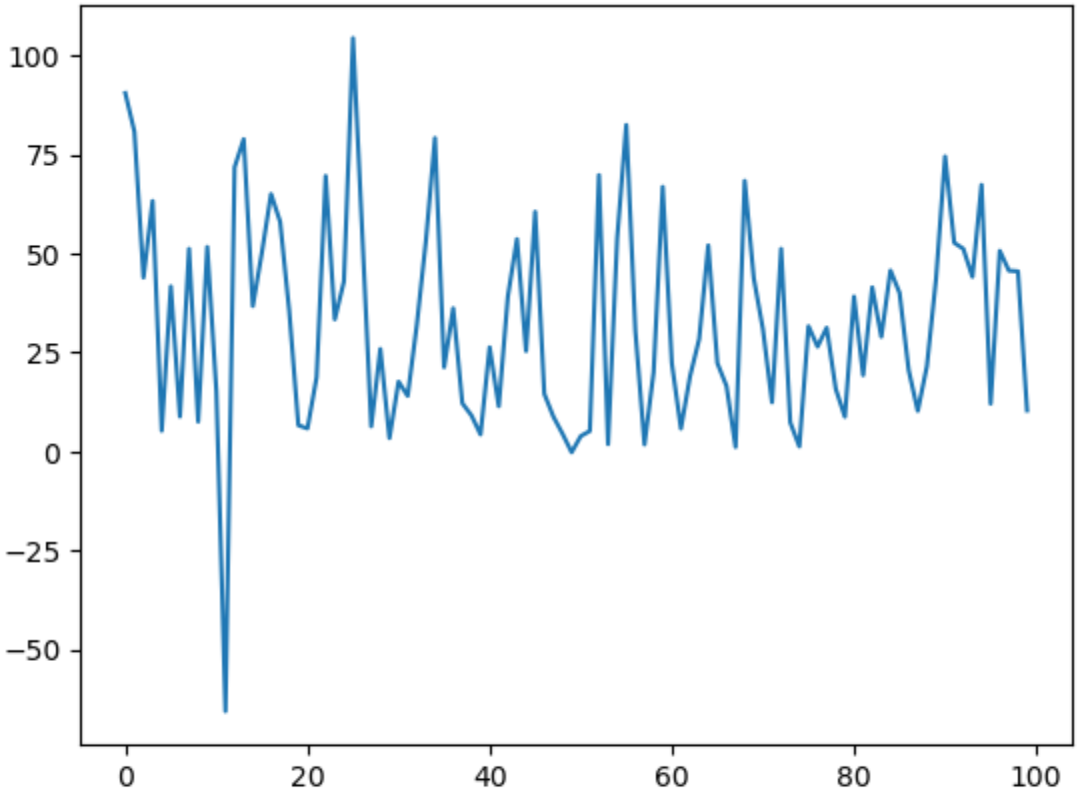
No Clipping and No GAE

In [46]:
```
N = 100 # number of times to collect new trajectories and update actor
M = 1 # num of trajectories
max_trajectory_len = 200 # trajectory length
batch_size = 25 # size for minibatch
n_epochs = 30 # number of epochs to optimize loss
alpha = 0.0001
hidden_layers = 2
hidden_dims = 64
gamma = 0.7
lmbda = 0.9
clip_value = 0.1
use_gae = False
use_clip = False
n_critic = 5

total_losses, observations, loss_list, reward_list = ppo(
    N, M, max_trajectory_len, batch_size, alpha, hidden_layers, hidden_dims,
    gamma, lmbda, clip_value, use_gae, use_clip, n_critic)
```

In [47]:
```
tmp = [x for x in range(100)]
```

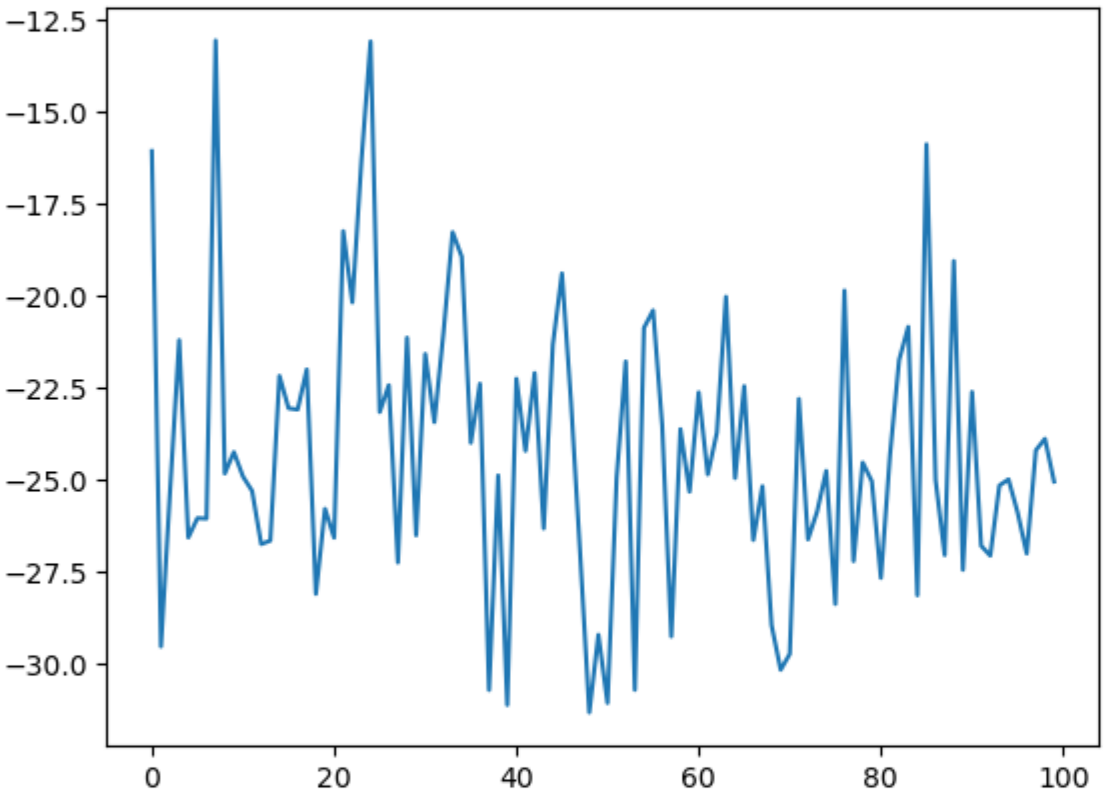
In [48]:
```
plt.plot(tmp, np.array([l.cpu().detach() for l in loss_list]))
```

Out[48]:
```
[<matplotlib.lines.Line2D at 0x18a96027130>]
```



In [49]:
```
plt.plot(tmp, np.array([l.cpu().detach() for l in reward_list]))
```

Out[49]: [<matplotlib.lines.Line2D at 0x18bcec70a90>]



In [50]:
```
o = []
for i in range(N):
    o.append(observations[200*(i+1)-200:200*(i+1)])
```

In [51]:
```
o_old = o.copy()
o = [j for i, j in enumerate(o) if i%10==0]
```

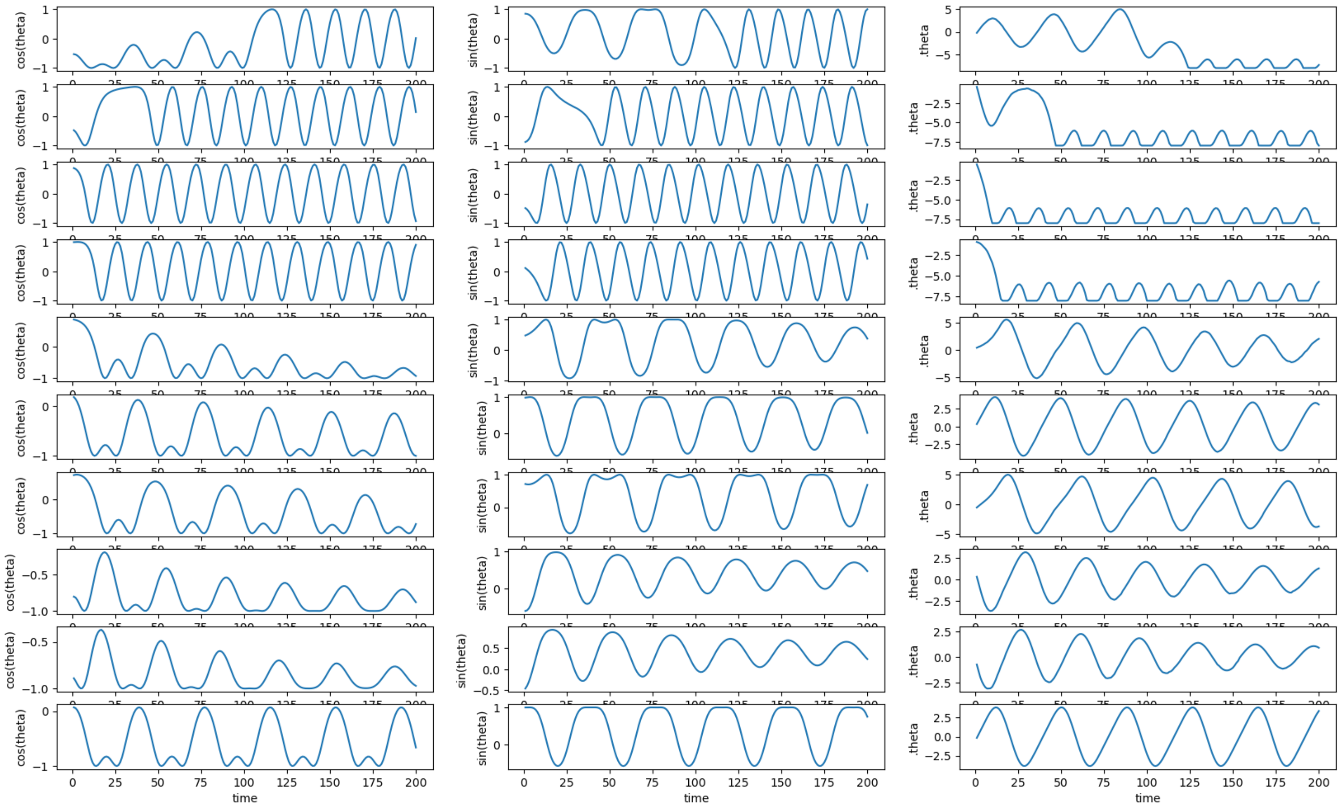
In [52]:
```
o = o_old[-10:]
```

In [53]:
```
x_ = [i+1 for i in range(200)]
```

In [54]:
```
np.array(o).shape
```

Out[54]: (10, 200, 3)

In [55]:
```
N = 10
plt.figure(1, figsize=(20, 12))
for i in range(N):
    obs = o[i]
    # print(obs)
    theta_ = []
    x_list = []
    y_list = []
    for x,y,v in obs:
        # print(x, y)
        theta_.append(v)
        x_list.append(x)
        y_list.append(y)
    plt.subplot(N, 3, 3*i+1)
    plt.plot(x_, x_list)
    plt.xlabel('time')
    plt.ylabel('cos(theta)')
    plt.subplot(N, 3, 3*i+2)
    plt.plot(x_, y_list)
    plt.xlabel('time')
    plt.ylabel('sin(theta)')
    plt.subplot(N, 3, 3*i+3)
    plt.plot(x_, theta_)
    plt.xlabel('time')
    plt.ylabel('.theta')
```



In [56]:
```
len(total_losses)
```

Out[56]: 24000

In [57]:
```
x = np.arange(len(total_losses))
y = [float(x) for x in total_losses]
plt.figure(figsize=(8, 6))
plt.plot(x, y)
```

Out[57]: [<matplotlib.lines.Line2D at 0x18b14b5c2e0>]