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Perform Pose Estimation using Computer Vision

Pose estimation is a popular task in Computer Vision. As a field of artificial intelligence (AI), computer vision enables machines to perform image processing tasks with the aim of imitating human vision.

This article provides an easy-to-read guide about the latest pose estimation methods in AI vision.

What is pose estimation?

Human pose estimation and tracking is a computer vision task that includes detecting, associating, and tracking semantic key points. Examples of semantic keypoints are “right shoulders”, “left knees” or the “left brake lights of vehicles”.

The performance of semantic keypoint tracking in live video footage requires high computational resources what has been limiting the accuracy of pose estimation. With the latest advances, new applications with real-time requirements become possible, such as self-driving cars and last-mile delivery robots.

Today, the most powerful image processing models are based on convolutional neural networks (CNNs). Hence, state-of-the-art methods are typically based on designing the CNN architecture tailored particularly for human pose inference.

Bottom-up vs. Top-down methods

All approaches for pose estimation can be grouped into bottom-up and top-down methods.

- **Bottom-up methods** estimate each body joint first and then group them to form a unique pose. Bottom-up methods were pioneered with DeepCut (a method we will cover later in more detail).
- **Top-down methods** run a person detector first and estimate body joints within the detected bounding boxes.

The importance of Pose Estimation

In traditional object detection, people are only perceived as a bounding box (a square). By performing pose detection and pose tracking, computers can develop an

understanding of human body language. However, conventional pose tracking methods are neither fast enough nor robust enough to occlusions to be viable.

High-performing real-time pose detection and tracking will drive some of the biggest trends in computer vision. For example, tracking the human pose in real-time will enable computers to develop a finer-grained and more natural understanding of human behavior.

This will have a big impact on various fields, for example, in autonomous driving. Today, the majority of self-driving car accidents are caused by "robotic" driving, where the self-driving vehicle conducts an allowed but unexpected stop, and a human driver crashes into the self-driving car. With real-time human pose detection and tracking, the computers are able to understand and predict pedestrian behavior much better – allowing more natural driving.

Examples of pose predictions on sports, professional and casual photos from the CrowdPose set. – Source

What is human pose estimation?

Human pose estimation aims at predicting the poses of human body parts and joints in images or videos. Since pose motions are often driven by some specific human actions, knowing the body pose of a human is critical for action recognition.

What is 2D Human Pose Estimation?

2D human pose estimation is used to estimate the 2D position or spatial location of human body keypoints from visuals such as images and videos. Traditional 2D human pose estimation methods use different hand-crafted feature extraction techniques for the individual body parts.

Early computer vision works described the human body as a stick figure to obtain global pose structures. However, modern deep learning based approaches have achieved major breakthroughs by improving the performance significantly for both single-person and multi-person pose estimation. Some popular 2D human pose estimation methods include OpenPose, CPN, AlphaPose, and HRNet (we will cover them and others later in this article).

Human pose estimation with deep learning

What is 3D Human Pose Estimation?

3D Human Pose Estimation is used to predict the locations of body joints in 3D space. Besides the 3D pose, some methods also recover 3D human mesh from images or videos. This field has attracted much interest in recent years since it is used to provide extensive 3D structure information related to the human body. It can be applied to various applications, such as 3D animation industries, virtual or

augmented reality, and 3D action prediction. 3D human pose estimation can be performed on monocular images or videos (normal camera feeds).

Using multiple viewpoints or additional sensors (IMU or LiDAR), 3D pose estimation can be applied with information fusion techniques, which is a very challenging task. While 2D human datasets can be easily obtained, collecting accurate 3D pose image annotation is time-consuming, and manual labeling is not practical and expensive. Therefore, although 3D pose estimation has made significant advancements in recent years, especially due to the progress made in 2D human pose estimation, there are still several challenges to overcome: Model generalization, robustness to occlusion, and computation efficiency.

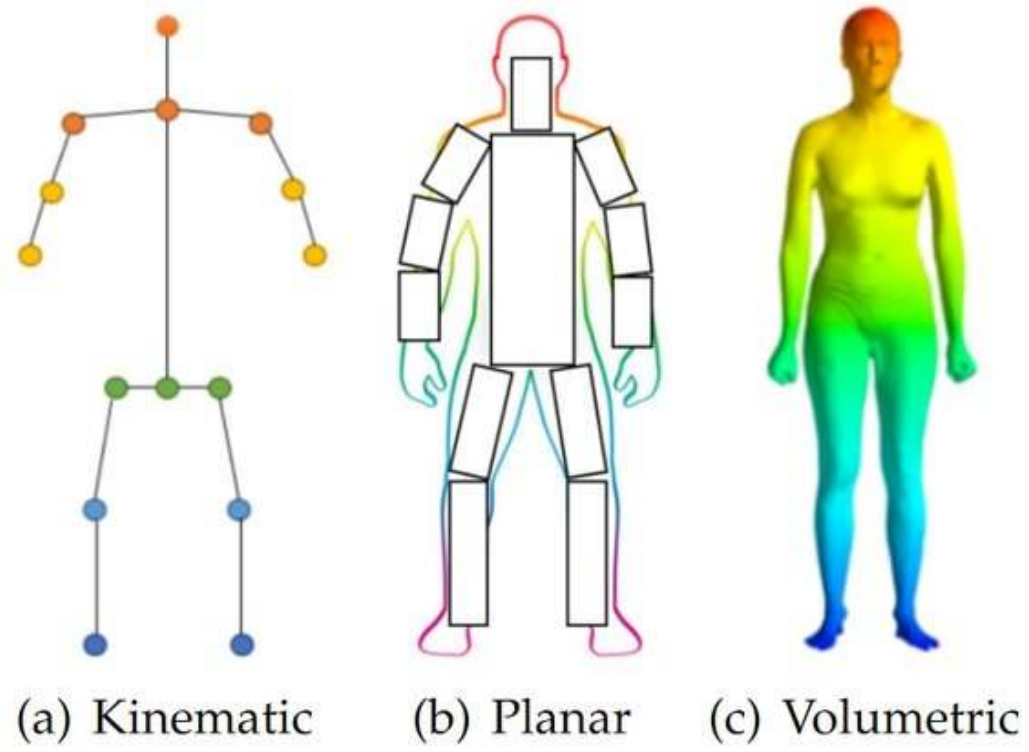
Human body modeling

In human pose estimation, the location of human body parts is used to build a human body representation (such as a body skeleton pose) from visual input data. Therefore, human body modeling is an important aspect of human pose estimation. It is used to represent features and keypoints extracted from visual input data. Typically, a model-based approach is used to describe and infer human body poses and render 2D or 3D poses.

Most methods use an N-joints rigid kinematic model where a human body is represented as an entity with joints and limbs, containing body kinematic structure and body shape information.

There are three types of models for human body modeling:

- **Kinematic Model**, also called skeleton-based model, is used for 2D pose estimation as well as 3D pose estimation. This flexible and intuitive human body model includes a set of joint positions and limb orientations to represent the human body structure. Therefore, skeleton pose estimation models are used to capture the relations between different body parts. However, kinematic models are limited in representing texture or shape information.
- **Planar Model**, or contour-based model, that is used for 2D pose estimation. The planar models are used to represent the appearance and shape of a human body. Usually, body parts are represented by multiple rectangles approximating the human body contours. A popular example is the Active Shape Model (ASM) that is used to capture the full human body graph and the silhouette deformations using principal component analysis.
- **Volumetric model**, which is used for 3D pose estimation. There exist multiple popular 3D human body models used for deep learning based 3D human pose estimation for recovering 3D human mesh. For example, GHUM & GHUML(ite), are fully trainable end-to-end deep learning pipelines trained on a high-resolution dataset of full-body scans of over 60’000 human configurations to model statistical and articulated 3D human body shape and pose. It can be used to infer



Human Pose Modeling: The three types of models for human body modeling – Source

Main challenges

Human pose estimation is a challenging task as the body's appearance joins changes dynamically due to diverse forms of clothes, arbitrary occlusion, occlusions due to the viewing angle, and background contexts. Pose estimation needs to be robust to challenging real-world variations such as are lighting and weather.

Therefore, it is challenging for image processing models to identify the fine-grained joint coordinates. It is especially difficult to track small and barely visible joints.

Head pose estimation

Estimating the head pose of a person is a popular computer vision problem. Head pose estimation has multiple applications such as aiding in gaze estimation, modeling attention, fitting 3D models to video and performing face alignment.

Traditionally head pose is computed with the use of keypoints from the target face and by solving the 2D to 3D correspondence problem with a mean human head model.

The ability to recover the 3D pose of the head is a by-product of keypoint-based facial expression analysis that is based on the extraction of 2D facial keypoints with deep learning methods. Those methods are robust to occlusions and extreme pose changes.

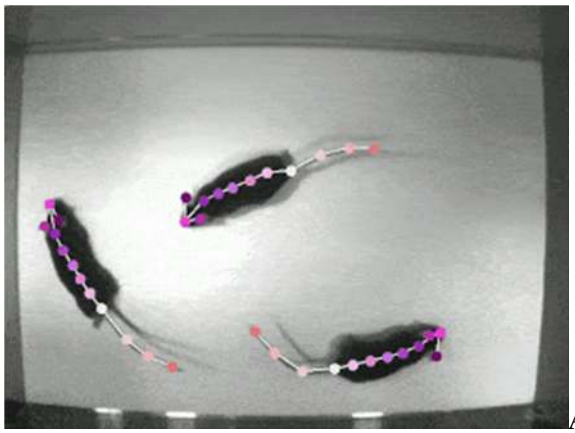
Animal pose estimation

Most state-of-the-art methods focus on human body pose detection and tracking. However, some models were developed to be used with animals and cars (object pose estimation).

Animal pose estimation comes with additional challenges such as limited labeled data (need to annotate images manually) and a large number of self-occlusions. Therefore, datasets for animals are usually small and include limited animal species.

Also, estimating the pose of multiple animals is a challenging computer vision problem due to frequent interactions that cause occlusions and complicate assigning detected key points to the correct individual. Also, it is challenging to have very similar-looking animals that interact more closely than humans typically would.

To address those issues, transfer learning techniques have been developed to re-apply methods from humans to animals. An example is multi-animal pose estimation and tracking with DeepLabCut, a state-of-the-art, popular open-source pose estimation toolbox for animals and humans.


Animal Pose Estimation and Pose Tracking with DeepLabCut – Source

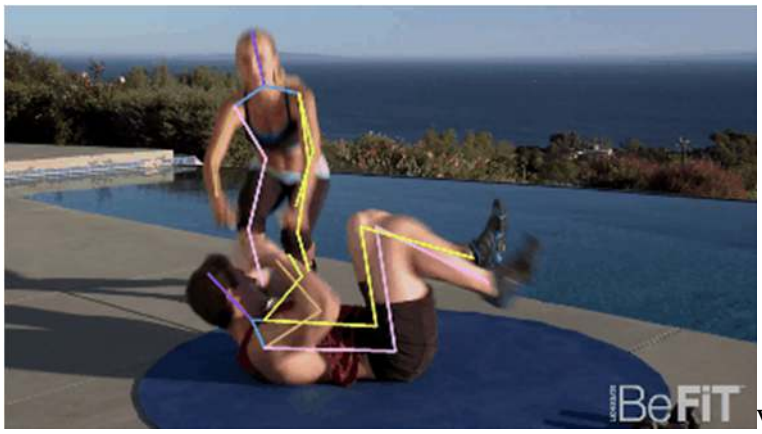
Video person pose tracking

Multi-frame human pose estimation in complicated situations is complex and requires high computing power. While human joints detectors show good performance for static images, their performances often come short when the models are applied to video sequences for real-time pose tracking.

The biggest challenges include handling motion blur, video defocus, pose occlusions, and the inability to capture temporal dependency among video frames.

Applying conventional recurrent neural networks (RNN) incurs empirical difficulties in modeling spatial contexts, especially for dealing with pose occlusions. State-of-

the-art multi-frame human pose estimation frameworks, such as DCPose, leverage abundant temporal cues between video frames to facilitate keypoint detection.



Video-based human pose detection – Source

How does Pose Estimation work?

Pose estimation utilizes pose and orientation to predict and track the location of a person or object. Accordingly, pose estimation allows programs to estimate spatial positions ("poses") of a body in an image or video. In general, most pose estimators are 2 steps frameworks that detect human bounding boxes and then estimate the pose within each box.

Pose estimation operates by finding key points of a person or object. Taking a person, for example, the key points would be joints like the elbow, knees, wrists, etc. There are two types of pose estimation: multi-pose and single pose. Single pose estimation is used to estimate the poses of a single object in a given scene, while multi-pose estimation is used when detecting poses for multiple objects.

Human pose estimation on the popular MS COCO Dataset can detect 17 different keypoints (classes). Each keypoint is annotated with three numbers (x,y,v), where x and y mark the coordinates, and v indicates if the keypoint is visible.

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"nose", "left_eye", "right_eye", "left_ear", "right_ear", "left_shoulder", "right_shoulder", "left_elbow", "right_elbow",
"left_wrist", "right_wrist", "left_hip", "right_hip", "left_knee", "right_knee", "left_ankle", "right_ankle"
```

Keypoints detected by OpenPose on the Coco Dataset – Source: Lin et al. 2014

Pose Estimation with Deep Learning

With the rapid development of deep learning solutions in recent years, deep learning has been shown to outperform classical computer vision methods in various tasks, including image segmentation or object detection. Therefore, deep learning techniques brought significant advances and performance gains in pose estimation tasks.

Next, we will list and review the popular pose estimation methods.

The Most popular Pose Estimation methods

- Method #1: High-Resolution Net (HRNet)
- Method #2: OpenPose
- Method #3: DeepCut
- Method #4: Regional Multi-Person Pose Estimation (AlphaPose)
- Method #5: Deep Pose
- Method #6: PoseNet
- Method #7: Dense Pose

Deep Learning based Pose Estimation methods

Because pose estimation is an easily applicable computer vision technique, we can implement a custom pose estimator using existing architectures. The existing architectures for getting you started with developing a custom pose estimator include:

1. High-Resolution Net (HRNet) is a neural network for human pose estimation. It is an architecture used in image processing problems to find what we know as key-points (joints) with respect to the specific object or person in an image. One advantage of this architecture over other architectures is that most existing methods match high-resolution representations of postures from low-resolution representations with respect to using high-low resolution networks. In place of this bias, the neural network maintains high-resolution representations when estimating postures. For instance, this HRNet architecture is helpful for the detection of human posture in televised sports.
2. OpenPose is one of the most popular bottom-up approaches for multi-person human pose estimation. This architecture features real-time, multi-person pose estimation. OpenPose is an open-sourced real-time multi-person detection, with high accuracy in detecting body, foot, hand, and facial keypoints. An advantage of OpenPose is that it is an API that gives users the flexibility of selecting source images from camera fields, webcams, and others, more importantly for embedded system applications (for instance, integration with CCTV cameras and systems). It supports different hardware architectures, such as CUDA GPUs, OpenCL GPUs, or CPU-only devices.
3. DeepCut is another popular bottom-up approach for multi-person human pose estimation. DeepCut is used for detecting the poses of multiple people. The model works by detecting the number of people in an image and then predicting the joint locations for each image. DeepCut can be applied to videos or images with multi-persons/objects, for example, football, basketball, and more.
4. Regional Multi-Person Pose Estimation (AlphaPose) is a popular top-down method of pose estimation. It is useful for detecting poses in the presence of inaccurate human bounding boxes. That is, it is an optimal architecture for estimating human poses via optimally detected bounding boxes. AlphaPose architecture is applicable for detecting both single and multi-person poses in images or video fields.
5. DeepPose: This is a human pose estimator that leverages the use of deep neural networks. The deep neural network (DNN) of DeepPose captures all joints, hinges a pooling layer, a convolution layer, and a fully-connected layer to form part of these layers.
6. PoseNet: PoseNet is a pose estimator architecture built on tensorflow.js to run on lightweight devices such as the browser or mobile device. Hence, PoseNet can be used to estimate **either** a **single pose** or **multiple poses**.
7. DensePose: This is a pose estimation technique that aims at mapping all human pixels of an RGB image to the 3D surface of the human body.

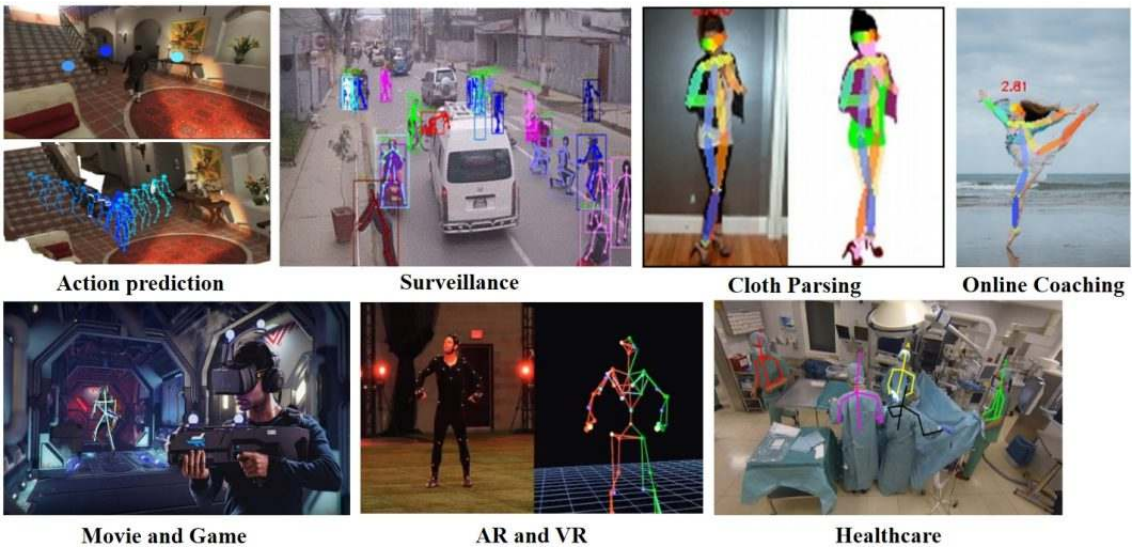
DensePose can also be used for single and multiple pose estimation problems.

Use Cases and Applications of Pose Estimation

Human pose estimation has been utilized in a wide range of applications, including human-computer interaction, motion analysis, augmented reality, and robotics.

Pose estimation has applications in lots of fields, some of which are listed below:

1. Human Activity Estimation
2. Motion Transfer and Augmented Reality
3. Training Robots
4. Motion Tracking for Consoles
5. Human Fall Detection



Various Human Pose Estimation Applications in Computer Vision – Source

Human Activity Estimation: A rather obvious application of pose estimation is tracking and measuring human activity and movement. Architectures like DensePose, PoseNet, or OpenPose are often used for activity, gesture, or gait recognition. Examples of human activity tracking via the use of pose estimation include:

- Application for detecting sitting gestures
- Full body/sign language communication (for example, traffic policemen signals)
- Applications to detect if a person has fallen down or is sick

- Applications to support the analysis of football, basketball, and sports
- Applications to analyze dance techniques (for example, in ballet dances)
- Application of posture learning for body works and finesses
- Applications in security and surveillance enhancement

Example of a Pose Estimation Use Case

Augmented Reality and Virtual Reality: As of today, pose estimation interfaced with augmented and virtual reality applications gives users a better online experience. For instance, users can virtually learn how to play games like tennis via virtual tutors who are pose represented.

More so, pose estimators can also be interfaced with augmented reality-based applications. For example, The United States Army experiments with augmented reality programs to be used in combat. These programs aim to help soldiers distinguish between enemies and friendly troops, as well as improve night vision.

Training Robots: Typical use cases of pose estimators is in the application of making robots learn certain crafts. In place of manually programming robots to follow trajectories, robots can be made to learn actions and movements by following the tutor's posture look or appearance.

Motion Tracking for Consoles: Other applications of pose estimation are in-game applications, where human subjects auto-generate and inject poses into the game environment for an interactive gaming experience. For instance, Microsoft's Kinect used 3D pose estimation (using IR sensor data) to track the motion of the human players and to use it to render the actions of the characters virtually into the gaming environment.