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Contents

Abstract

This REP provides a set of conventions and common interfaces for Human-Robot Interaction (HRI) scenarios, with a focus on the perception of humans and social signals. It aims at enabling interoperability and reusability of core functionality between the many HRI-related software tools, from skeleton tracking, to face recognition, to natural language processing.

Besides, these interfaces are designed to be relevant for a broad range of HRI situations, from crowd simulation, to kineastetic teaching, to social interaction.

Specifically, this REP covers:

- human modeling, as a combination of a permanent identity (person) and transient parts that are intermittently detected (eg face, skeleton, voice);
- topic naming conventions under the `/humans/` topic namespace;
- human kinematic modeling (based on dynamically generated URDF models), as well as 3D TF frame conventions (naming, orientation);
- representation of group interactions (groups, mutual gaze)

Rationale

ROS is widely used in the context of human-robot interactions (HRI). However, to date, not a single effort (e.g. [1] [2]) has been successful at coming up with broadly accepted interfaces and pipelines for that domain, as found in other parts of the ROS ecosystem (for manipulation or 2D navigation for instance). As a result, many different implementations of common tasks (skeleton tracking, face recognition, speech processing, etc) cohabit, and while they achieve similar goals, they are not generally compatible, hampering the code reusability, experiment replicability, and general sharing of knowledge.

In order to address this issue, this REP aims at structuring the whole "ROS for HRI" space by creating an adequate set of ROS messages and services to describe the software interactions relevant to the HRI domain, as well as a set of convention (eg topics structure, tf frames) to expose human-related information.

The REP aims at modeling these interfaces based on existing, state-of-the-art algorithms relevant to HRI perception, while considering the broad range of application scenario in HRI.

It is hoped that such an effort will allow easier collaboration between projects and allow a reduction in duplicate efforts to implement the same functionality.

Overview

This REP specifies multiple aspects of human-robot interaction, with a primary focus on human perception/social signal recognition.

It is split into 4 sections:

1. human representation, as a combination of a permanent identity (*person*) and transient parts that are intermittently detected (e.g. *face*, *skeleton*, *voice*);
2. topic naming conventions under the `/humans/` topic namespace;
3. kinematic model of the human and 3D tf frame conventions (naming, orientation, compatible with REP-120 [3] where possible)
4. representation of group interactions (groups, mutual gaze)

By following the naming conventions and leveraging the interfaces defined in this REP, both tools and libraries can be designed to be reusable between different frameworks and experiments.

> **Note**
>
> Importantly, the REP does not mandate specific tools or algorithms to perform human perception/social signal recognition per se. It only specify naming conventions and interfaces between these nodes.

Human Representation

To accommodate existing tools and technique used to detect and recognise humans, the representation of a person is build on a combination of 4 unique identifiers (UUIDs): a **person identifier**, a **face identifier**, a **body identifier** and a **voice identifier**. Future revisions of this REP might add additional identifiers.

These four identifiers are not mutually exclusive, and depending on the requirements of the application, the available sensing capabilities, and the position/behaviour of the humans, only some might be available for a given person, at a given time.

Person Identifier

The **person identifier** MUST be a unique ID (typically, a UUID) permanently associated with a unique person. This person ID is normally assigned by a module able to perform person identification (face recognition module, voice recognition module, sound source localisation + name, identification based on physical features like height/age/gender, person identification based on pre-defined features like the colour of the clothes, etc.) This ID is meant to be **persistent** so that the robot can recognise people across encounters/sessions. Nodes providing person IDs might even consider serialising these IDs for them to persist across e.g. robot reboots.

As soon as a face, a body or a voice is detected, the robot can infer the presence of a person, and therefore a person ID MUST be created and associated with that face/body/voice. As person IDs are permanent, that ID will permanently remain in the robot's knowledge.

When meaningful (see section Person frame), a TF frame MUST be associated to the person ID and named `person_<personID>`. Due to the importance of the head in human-robot interaction, the `person_<personID>` frame is expected to be placed as close as possible to the head of the human. If neither the face nor the skeleton are tracked, the `person_<personID>` frame might be located to the last known position of the human, or removed altogether if no meaningful estimate of the human location is available. See below for details regarding the `person_<personID>` frame.

At any given time, the list of known persons is published under the `/humans/persons/tracked` topic as `hri_msgs/IdsList` messages.

Merging Person Identifiers

In certain cases, two person IDs must be merged (for instance, the robot detects that a voice and a face that were thought to belong to different people are indeed the same person).

In such a case, one of the person ID is marked as an *alias* of the other person, by publishing the ID of the other person on a special subtopic named `alias`. See section Topics structure for details.

> **Note**
>
> The reverse operation (spliting a person into two) can be realised by simply publishing a second person ID.

Face Identifier

The **face identifier** MUST be a unique ID that identifies a detected face. This ID is typically generated by the face detector/head pose estimator upon face detection.

Importantly, **this ID is not persistent**: once a face is lost (for instance, the person goes out of frame), its ID is not valid nor meaningful anymore. To cater for a broad range of applications (where re-identification might not be always necessary), there is no expectation that the face detector will attempt to recognise the face and re-assign the same face ID if the person re- appears.

> **Note**
>
> It is however permissible for a face detector/face tracker to re-use the same face ID if it is confident that the face if indeed the same.

There is a one-to-one relationship between this face ID and the estimated 6D pose of the head, represented as a ROS TF frame named `face_<faceID>` (see section Face frame for the face frame conventions).

At any given time, the list of tracked faces is published under the `/humans/faces/tracked` topic as `hri_msgs/IdsList` messages.

Body Identifier

Similarly to the face identifier, the **body identifier** MUST be a unique ID, associated to a person's skeleton. It is normally created by a skeleton tracker upon detection of a skeleton.

Like the face ID, **the body ID is not persistent**, and is valid only as long as the specific skeleton is tracked by skeleton tracker which initially detected it.

The corresponding TF frame is `body_<bodyID>`, and TF frames associated with each of the body parts of the person, are suffixed with the same ID (see section Body frames).

At any given time, the list of tracked bodies is published under the `/humans/bodies/tracked` topic as `hri_msgs/IdsList` messages.

Voice Identifier

Likewise, a speech separation module should assign a unique, non-persistent, ID for each detected voice. Tracked voices are published under the `/humans/voices/tracked` topic as `hri_msgs/IdsList` messages.

Identifier Matching

Associations between IDs (for instance to denote that a given voice belongs to a given person, or a given face to a given body) are expressed by publishing `hri_msgs/IdsMatch` messages on the `/humans/candidate_matches` topic. The `hri_msgs/IdsMatch` message includes a confidence level.

A typical implementation will have several specialised nodes publishing candidate matches on `/humans/candidate_matches` (e.g. a face recognition node providing matches between faces and persons; a voice recognition node providing matches between voices and persons) and one 'person manager' node collecting the candidates, and publishing the most likely associations between a person ID and its face/body/voice IDs under the `/humans/persons/` namespace.

Identifier Syntax

Identifiers can be arbitrary, as long as they are unique. It is also recommended to keep them short to avoid clutter. One reasonably simple way of generating random IDs with few collision is:

```
import uuid
id=str(uuid.uuid4())[:5] # for a 5 char long ID
```

Note that using people's names as identifier is possible, but not generally recommended as collisions are likely.

Global Parameters

- `/humans/faces/width` (default: 128): width in pixels of the cropped faces published under `/humans/faces/XYZ/cropped` and `/humans/faces/XYZ/frontalized`
- `/humans/faces/height` (default: 128): height in pixels of the cropped faces published under `/humans/faces/XYZ/cropped` and `/humans/faces/XYZ/frontalized`
- `/human_description_<bodyID>`: URDF models of detected humans. See Section Kinematic Model of the Human for details.

Topics Structure

A system implementing this REP is expected to follow the following conventions for all HRI-related topics:

1. all topics are grouped under the global namespace `/humans/`
2. five sub-namespaces are available:
    - `/humans/faces`
    - `/humans/bodies`
    - `/humans/voices`
    - `/humans/persons`
    - `/humans/interactions`
3. the first four (`/faces`, `/bodies`, `/voices`, `/persons`) expose one sub-namespace per face, body, voice, person detected, named after the corresponding ID (for instance, `/humans/faces/bd34a/`). In addition, they expose a topic `/tracked` (of type `hri_msgs/IdsList`) where the list of currently tracked faces/bodies/voices/persons is published;
4. matches between faces/bodies/voices/persons are published on the `/humans/candidate_matches` topic, as explained in Section Identifier matching;
5. the `/humans/interactions` topic exposes group- level signals, including gazing patterns and social groups.

> **Note**
>
> the `hri_msgs` messages are defined in the hri_msgs repository.

Note

The slightly unconvential structure of topics (with one namespace per face, body, person, etc.) enables modular pipelines.

For instance, a face detector might publish cropped images of detected faces under /humans/faces/face_1/cropped, /humans/faces/face_2/cropped, etc.

Then, depending on the application, an additional facial expression recognizer might be needed as well. For each detected faces, that node would subscribe to the corresponding */cropped* topic and publish its results under /humans/faces/face_1/expression, /humans/faces/face_2/expression, etc., augmenting the available information about each faces in a modular way.

Such modularity would not be easily possible if we add chosen to publish instead a generic Face message, as a single node would have had first to fuse every possible information about faces.

See the Illustrative Example below for a complete example.

Note

libhri can be used to hide away the complexity of tracking new persons/faces/bodies/voices. It automatically handles subscribing/unsubcribing to the right topics when new persons/faces/bodies/voices are detected.

Faces

The list of currently detected faces (list of face IDs) is published under /humans/faces/tracked (as a hri_msgs/IdsList message).

For each detected face, a namespace /humans/faces/<faceID>/ is created (eg /humans/faces/bf3d/).

The following subtopics might then available, depending on available detectors:

Name	Message type	Required	Description
/roi	sensor_msgs/RegionOfInterest	x	Region of the face in the source image
/cropped	sensor_msgs/Image	x	Cropped face image, if necessary scaled, centered and 0-padded to match the /humans/faces/width and /humans/faces/height ROS parameters
/frontalized	sensor_msgs/Image		Frontalized version of the cropped face, with same resolution as /cropped
/landmarks	hri_msgs/FacialLandmarks		2D facial landmarks extracted from the face
/facs	hri_msgs/FacialActionUnits		The presence and intensity of facial action units found in the face
/expression	hri_msgs/Expression		The expression recognised from the face

Bodies

The list of currently detected bodies (list of body IDs) is published under /humans/bodies/tracked (as a hri_msgs/IdsList message).

For each detected body, a namespace /humans/bodies/<bodyID>/ is created. The following subtopics might then available, depending on available detectors:

Name	Message type	Required	Description
/roi	sensor_msgs/RegionOfInterest	x	Region of the whole body body in the source image
/cropped	sensor_msgs/Image	x	Cropped body image
/skeleton2d	hri_msgs/Skeleton2D		The 2D points of the the detected skeleton
/joint_states	sensor_msgs/JointState		The joint state of the human body, following the Kinematic Model of the Human
/attitude	hri_msgs/BodyAttitude		Recognised body attitude or gesture

3D body poses are handled differently, via a joint state publisher and TF frames. Cf below.

Voices

The list of currently detected voices (list of voice IDs) is published under /humans/voices/tracked (as a hri_msgs/IdsList message).

For each detected voice, a namespace /humans/voices/<voiceID>/ is created.

The following subtopics might then available, depending on available detectors:

Name	Message type	Required	Description
/audio	audio_msgs/AudioData	x	Separated audio stream for this voice
/features	hri_msgs/AudioFeatures		INTERSPEECH'09 Emotion challenge [4] low-level audio features

Name	Message type	Required	Description
/is_speaking	std_msgs/Bool		Whether or not speech is recognised from this voice
/speech	hri_msgs/LiveSpeech		The live stream of speech recognized via an ASR engine

Persons

The list of currently detected persons (list of person IDs) is published under `/humans/persons/tracked` (as a `hri_msgs/IdsList` message).

For each detected person, a namespace `/humans/persons/<personID>/` is created.

The following subtopics might then available, depending on available detectors, and whether or not the person has been matched to a face/body/voice:

Name	Message type	Required	Description
/face_id	std_msgs/String (latched)		Face matched to that person (if any)
/body_id	std_msgs/String (latched)		Body matched to that person (if any)
/voice_id	std_msgs/String (latched)		Voice matched to that person (if any)
/alias	std_msgs/String (latched)		If this person has been merged with another, this topic contains the person ID of the new person
/engaged	std_msgs/Bool		if true, the person is considered to be currently engaged in an interaction with the robot
/location_confidence	std_msgs/Float32		Location confidence; 1 means *person currently seen*, 0 means *person location unknown*. See Person Frame
/softbiometrics	hri_msgs/SoftBiometrics		Detected age and gender of the person
/name	std_msgs/String		Name, if known
/native_language	std_msgs/String		IETF language codes like EN_gb, if known

Interactions

Finally, the namespace `/humans/interactions` exposes topics where group-level interactions are published when detected.

Name	Message type	Description
/groups	hri_msgs/Group	Estimated social groups
/gazing	hri_msgs/Gaze	Estimated gazing behaviours

See section Group-level Interactions for details.

Illustrative Example

You run a node `your_face_detector_node`. This node detects two faces, and publishes the corresponding regions of interest and cropped faces. The node effectively advertises and publishes onto the following topics:

```
> rostopic list
/humans/faces/23bd5/roi     # sensor_msgs/RegionOfInterest
/humans/faces/23bd5/cropped # sensor_msgs/Image
/humans/faces/b092e/roi     # sensor_msgs/RegionOfInterest
/humans/faces/b092e/cropped # sensor_msgs/Image
```

Note

The IDs (in this example, `23bd5` and `b092e`) are arbitrary, as long as they are unique. However, for practical reasons, it is recommended to keep them reasonably short.

You start an additional node to recognise expressions: `your_expression_classifier_node`. The node subscribes to the `/humans/faces/<faceID>/cropped` topics and publishes expressions for each faces under the same namespace:

```
> rostopic list
/humans/faces/23bd5/roi
/humans/faces/23bd5/cropped
/humans/faces/23bd5/expression # hri_msgs/Expression
/humans/faces/b092e/roi
/humans/faces/b092e/cropped
/humans/faces/b092e/expression # hri_msgs/Expression
```

You then launch `your_body_tracker_node`. It detects one body:

```
> rostopic list
/humans/faces/23bd5/...
```

```
/humans/faces/b092e/...
/humans/bodies/67dd1/roi     # sensor_msgs/RegionOfInterest
/humans/bodies/67dd1/cropped # sensor_msgs/Image
```

In addition, you start a 2D/3D pose estimator `your_skeleton_estimator_node`. The 2D skeleton can be published under the same body namespace, and the 3D skeleton is published as a joint state. The joint state can then be converted into TF frames using eg a URDF model of the human, alongside a `robot_state_publisher`:

```
> rostopic list
/humans/faces/23bd5/...
/humans/faces/b092e/...
/humans/bodies/67dd1/roi
/humans/bodies/67dd1/cropped
/humans/bodies/67dd1/skeleton2d # hri_msgs/Skeleton2D
/humans/bodies/67dd1/joint_states # sensor_msgs/JointState


> xacro ws/human_description/urdf/human-tpl.xacro id:=67dd1 height:=1.7 > body-67dd1.urdf
> rosparam set human_description_67dd1 -t body-67dd1.urdf
> rosrun robot_state_publisher robot_state_publisher joint_states:=/humans/bodies/67dd1/joint_states
robot_description:=human_description_67dd1
```

> **Note**
>
> In this example, we manually generate the URDF model of the human, load it to the ROS parameter server, and start a `robot_state_publisher`. In practice, this should be done programmatically everytime a new body is detected.

So far, faces and bodies are detected, but they are not yet 'unified' as a person.

First, we need a stable way to associate a face to a person. This would typically require a node for facial recognition. Such a node would subscribe to each of the detected faces' `/cropped` subtopics, and publish *candidate matches* on the `/humans/candidate_matches` topic, using a `hri_msgs/IdsMatch` message. For instance:

```
> rostopic echo /humans/candidate_matches
face_id: "23bd5"
body_id: ''
voice_id: ''
person_id: "76c0c"
confidence: 0.73
---
```

In that example, the person ID `76c0c` is created and assigned by the face recognition node itself.

Finally, you would need a `your_person_manager_node` to publish the `/humans/persons/76c0c/` subtopics based on the candidate matches:

```
> rostopic list
/humans/faces/23bd5/...
/humans/faces/b092e/...
/humans/bodies/67dd1/...
/humans/persons/76c0c/face_id
```

In this simple example, only the `/face_id` subtopic would be advertised (with a latched message pointing to the face ID `23bd5`). In practice, additional information could be gathered by the `your_person_manager_node` to expose eg soft biometrics, engagement, etc. Similarly, the association between the person and its body would have to be performed by a dedicated node.

Overall, six independent nodes are combined to implement this pipeline:

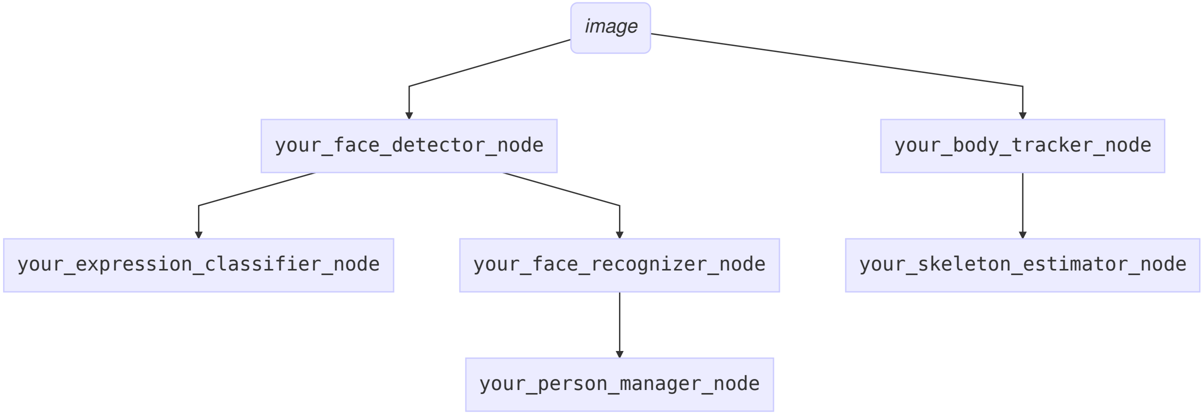


image
your_face_detector_node
your_body_tracker_node
your_expression_classifier_node
your_face_recognizer_node
your_skeleton_estimator_node
your_person_manager_node

This possible pipeline is only for illustration purposes: depending on each specific pipeline implementations, some of these nodes might be merged or on the contrary, further divided into smaller nodes. For instance, one might choose to integrate together the face recogniser node and the person manager.

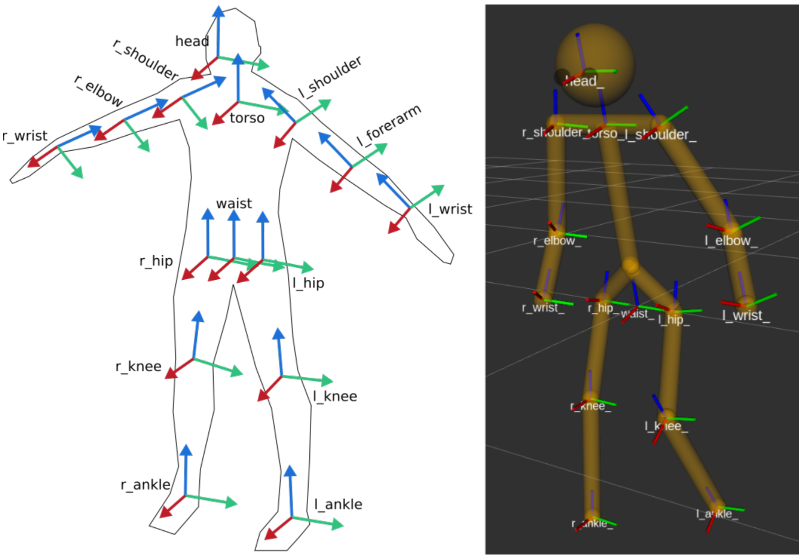
Note as well that, in order to build a complete perception pipeline for HRI, additional nodes would be needed, for instance for voice processing.

Kinematic Model and Coordinate Frames

Where meaningful, the coordinate frames used for humans follow the conventions set out in REP-120 [3].

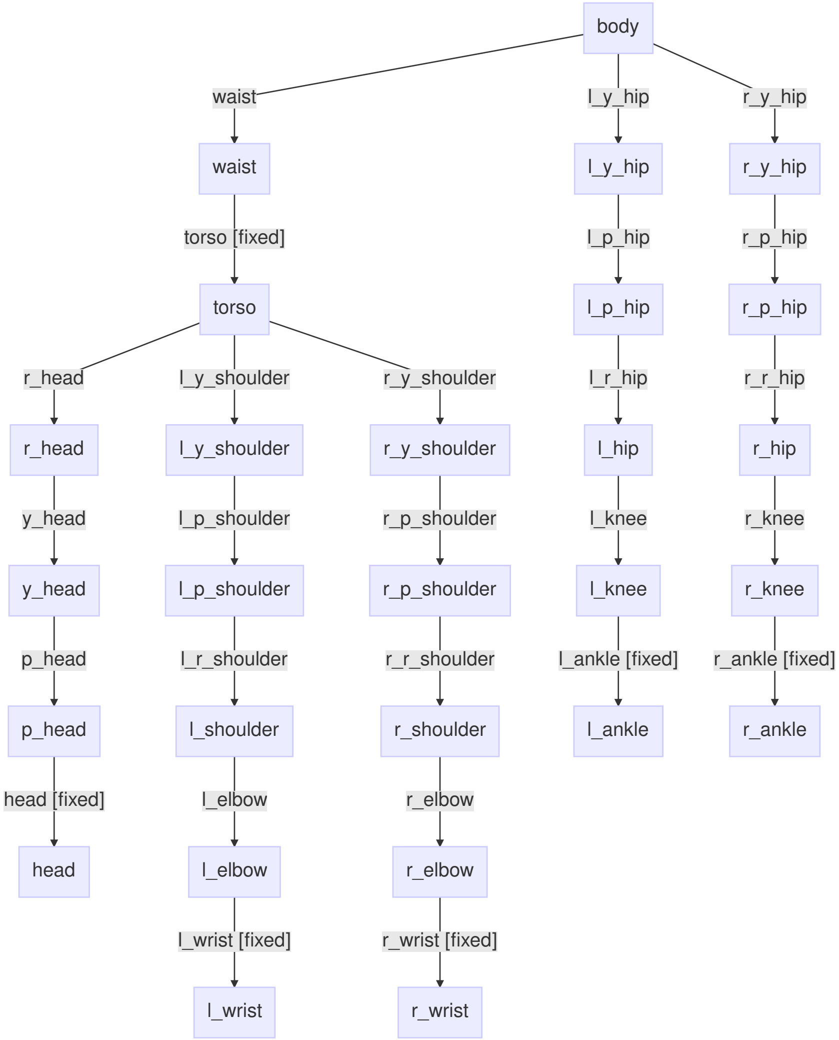
These conventions also follow the REP-103 [5].

Kinematic Model of the Human



The main 15 links defined on the human body. Frames orientations and naming are based on REP-103 and REP-120. Right: render of the reference URDF model of the human body in *rviz*.

The following diagram presents all the link (boxes) and joints (arrows) in the recommended human kinematic model.



In practice, each of these links and joints must be suffixed with the corresponding `bodyID`, as several skeletons might be present at the same time.

A parametric, reference URDF model of humans is available in the `human_description` package. It can be used to instanciate at run-time new human URDF model, adjusted for the e.g. height of the detected persons.

When generated, the URDF models of the humans should be loaded on the ROS parameter server under `/human_description_<bodyID>`.

> **Note**
>
> the human_description ROS package contains a launch script `visualize.launch` that can be used to quickly experiment with the kinematic model of humans.

Face Frame

- Head pose estimation modules are requested to publish head 6D pose as a TF frame named `face_<faceID>` where `<faceID>` stands for the unique face identifier.
- the parent of this frame is the sensor frame used to estimate the face pose.
- The origin of the frame must be the sellion (defined as the deepest midline point of the angle formed between the nose and forehead. It can generally be approximated to the mid point of line connecting the two eyes).
- The `x` axis is expected to point forward (ie, out of the face), the `z` axis is expected to point toward the scalp (ie, up when the person is standing vertically).
- Any other facial landmark published as a TF frame must be parented to the head TF frame. It should be suffixed with the same `_<faceID>`.

Body Frames

- The body frame is named `body_<bodyID>` where `<bodyID>` stands for the unique skeleton identifier.
- The origin of the frame is located at the mid point of the line connecting the hips.
- the parent of this frame is the sensor frame used to estimate the body pose.
- The `x` axis is expected to point forward (ie, out of the body), the `z` axis is expected to point toward the head (ie, up when the person is standing vertically).
- The other skeleton points published as TF frames must be parented to the root `body_<bodyID>` frame, and all be suffixed with the same `_<bodyID>`. Section Kinematic Model of the Human lists the recommended names of body links and body joints.
- if the skeleton tracker provide an estimate of the head pose, it might publish a frame named `head_<bodyID>`. *It is the joint responsibility of the face tracker and skeleton tracker to ensure that* `face_<faceID>` *and* `head_<bodyID>` *are consistent with each other.*

Voice Frame

- Sound source localisation algorithms can broadcast estiamted TF frames for detected voices. These frames should be named `voice_<voiceID>`.
- The orientation of the frame is meaningless, and should be ignored.

Person Frame

The `person_<personID>` frame has a slightly more complex semantic and must be interpreted in conjunction with the person's `location_confidence` value (see Persons topics).

We can distinguish four cases:

1. The person has not yet been identified, no `personID` has been assigned yet. In that case, no TF frame is published. In other words, **the TF frame** `person_<personID>` can only exist once the person has been recognised.
2. The human is currently being tracked (ie `personID` is set, and at least one of `faceID` or `bodyID` is set). In this case, `location_confidence` MUST be set to 1 and:
    - when a face ID is also defined, the `person_<personID>` frame must be collocated with the `face_<faceID>` frame.
    - when a body ID is defined (ie the skeleton is being tracked), the `person_<personID>` frame must be collocated with the skeleton frame the closest to the head.
    - if both the face and body IDs are defined, the `person_<personID>` frame must be collocated with the `face_<faceID>` frame.
3. The human is not seen, but has been previously seen. In this case, `location_confidence` MUST be set to a value `< 1` and a `person_<personID>` TF frame MUST be published **as long as** `location_confidence > 0`. Simple implementations might choose to set `location_confidence = 0.5` as soon as the person is not actively seen anymore, continuously broadcast the last known location. More advanced implementations might slowly decrease `location_confidence` over time to represent the fact that the human might have walked away, for instance.
4. The human is known, but has never been seem before. In this case, `location_confidence` MUST be set to `0`, and no TF frame should be broadcast.

Group-level Interactions

Representation of Groups

When detected, group-level interactions are published on the `/humans/interactions/groups`, using the `hri_msgs/Group.msg` message type.

Each group is defined by a unique group ID, and a list of person IDs. (groups can only be defined between persons).

Representation of gazing behaviours

Social gazing (eg, gazing between people) is represented as `hri_msgs/Gaze.msg` messages, published on the `/humans/interactions/gazing` topic.

Each `Gaze.msg` messages contain a *sender* and a *receiver* that MUST be known persons. Note that the relationship is not symmetrical: "A gazes at B" does not imply "B gazes at A". As such, *mutual gaze* will lead to two messages being published.

If one or the other of the sender and receiver IDs are not set, the robot is assumed to respectively originate or be the target of the gaze.

Nodes publishing gazing information are expected to continuously publish gaze messages, until the person is not gazing to the target anymore.

References

[1] `people` package, last commit in 2015 (https://github.com/wg-perception/people)

[2] `cob_people_perception` package, mainly developed between 2012 and 2014 (https://github.com/ipa320/cob_people_perception)

[3] *(1, 2)* REP 120, Coordinate Frames for Humanoid Robots (https://ros.org/reps/pep-0120.html)

[4] *The INTERSPEECH 2009 emotion challenge*, Schuller, Steidl and Batliner, Tenth Annual Conference of the International Speech Communication Association, 2009

[5] REP 103, Standard Units of Measure and Coordinate Conventions (http://www.ros.org/reps/rep-0103.html)

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