FidMark: A Fiducial Marker Ontology For Semantically Describing Visual Markers

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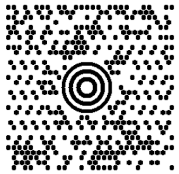
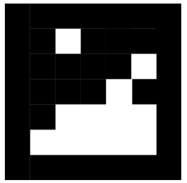
DMARK

Background – Fiducial Marker

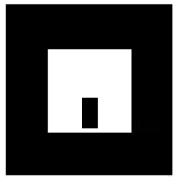


(a) Maxicode [2], 1992

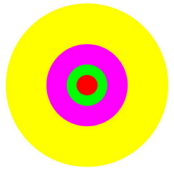
(b) QR code, 1994



(c) Matrix [38], 1998



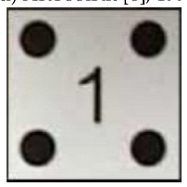
(d) ARToolKit [6], 1999



(e) Cho and Neumann [39], 2001

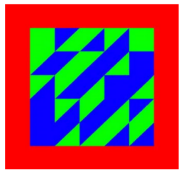
(f) TRIPtag [43], 2002

(g) Naimark and Foxlin [44], 2002



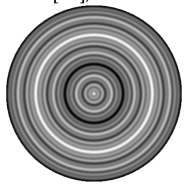
(h) Claus and Fitzgibbon [46], 2004

(i) ARTag [7], 2005

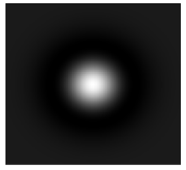


(j) Dell'Acqua et al. [48], 2005

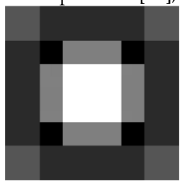
(k) reacTIVision [9], 2007



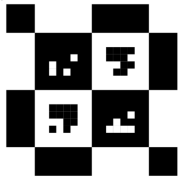
(l) Fourier Tag [51], 2007



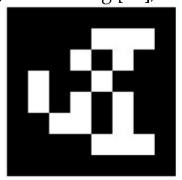
(m) Schweiger et al. [53], SIFT, 2009



(n) Schweiger et al. [53], SURF, 2009



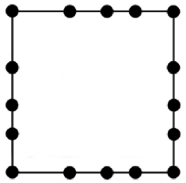
(o) CALTag [10], 2010



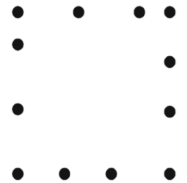
(p) AprilTag [11], 2011

(q) RUNE-Tag [14], 2011

(r) BlurTags [57], 2012



(s) CoP-Tag [58], 2012



(t) Pi-Tag [15], 2013

Košťák, M.; Slabý, A. Designing a Simple Fiducial Marker for Localization in Spatial Scenes Using Neural Networks. *Sensors* 2021, *21*, 5407.

(a) Liu et al. [59], 2013

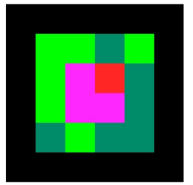
(b) Mono-spectrum marker [60], 2013

(c) Garrido-Jurado et al. [61], 2014

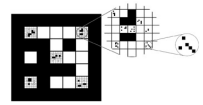
(d) BullsEye [64], 2014

(e) Prasad et al. [65], 2015

(f) CCTag [16], 2016

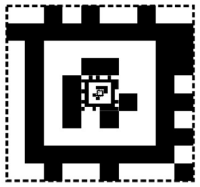


(g) ChromaTag [17], 2017

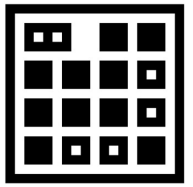


(h) HArCo [68], 2018

(i) STag [73], 2019



(j) Krogius et al. [13], 2019



(k) TopoTag [18], 2020

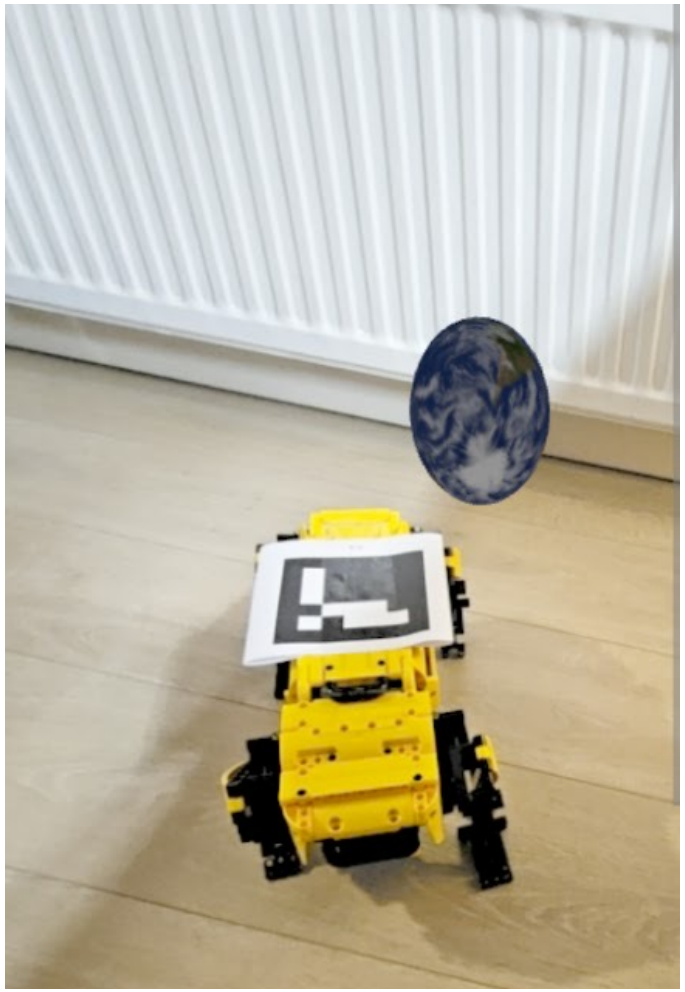
(l) LFTag [75], 2020

Problem

"How can we pave the way towards interoperable AR applications?"

How can we define a common reference frame between two independent augmented reality frameworks?

How can we define this common reference frame using a wide range of fiducial markers?

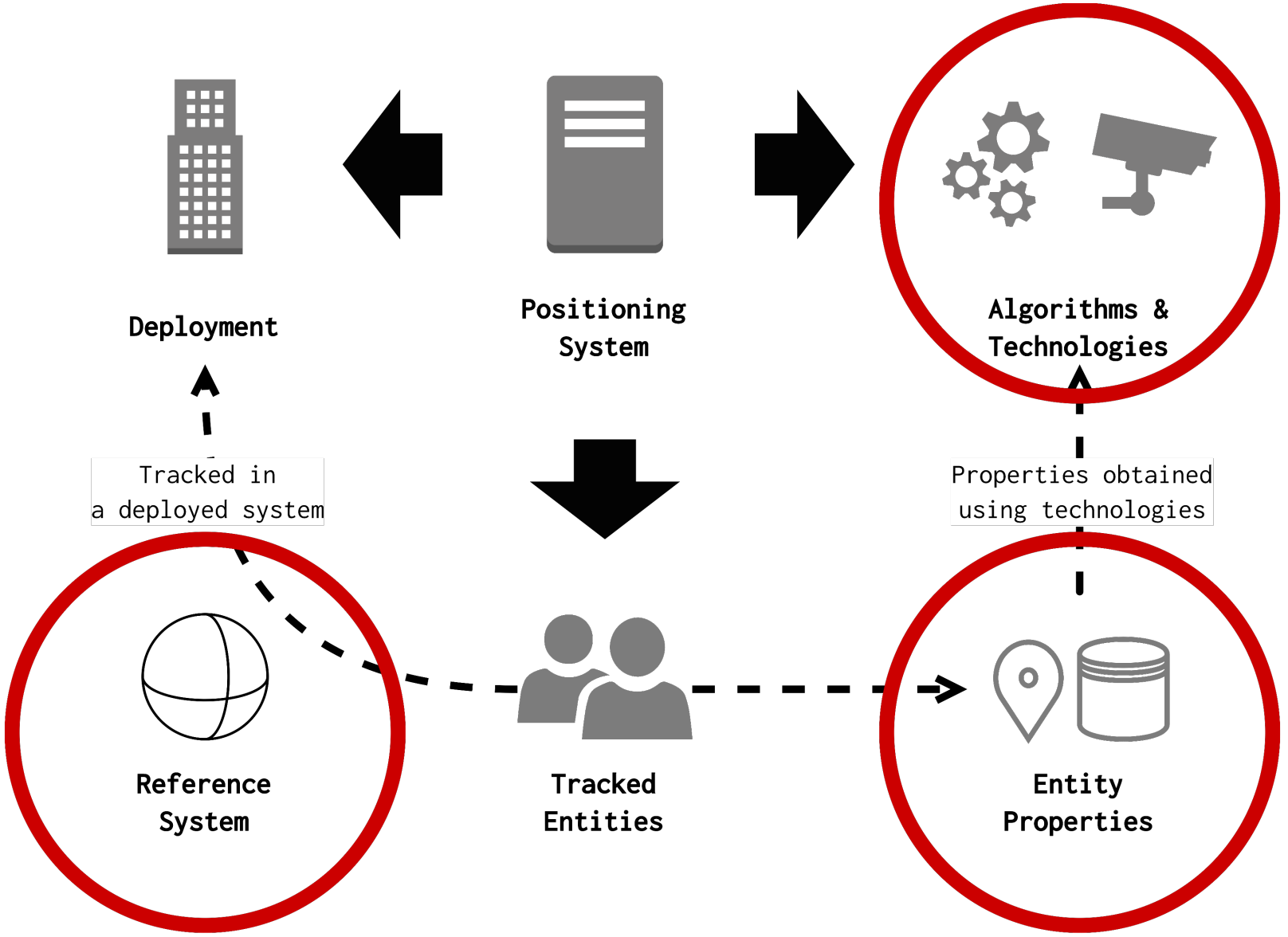


Methodology

1. Identification of **existing ontologies**
2. Identification of **existing frameworks**
3. Identification of common **markers types** (and variations)
4. **Design goals** based on problem statement
5. **Design** of ontology
6. **Validation** of the design goals using SPARQL queries
7. **Integration** testing of the ontology

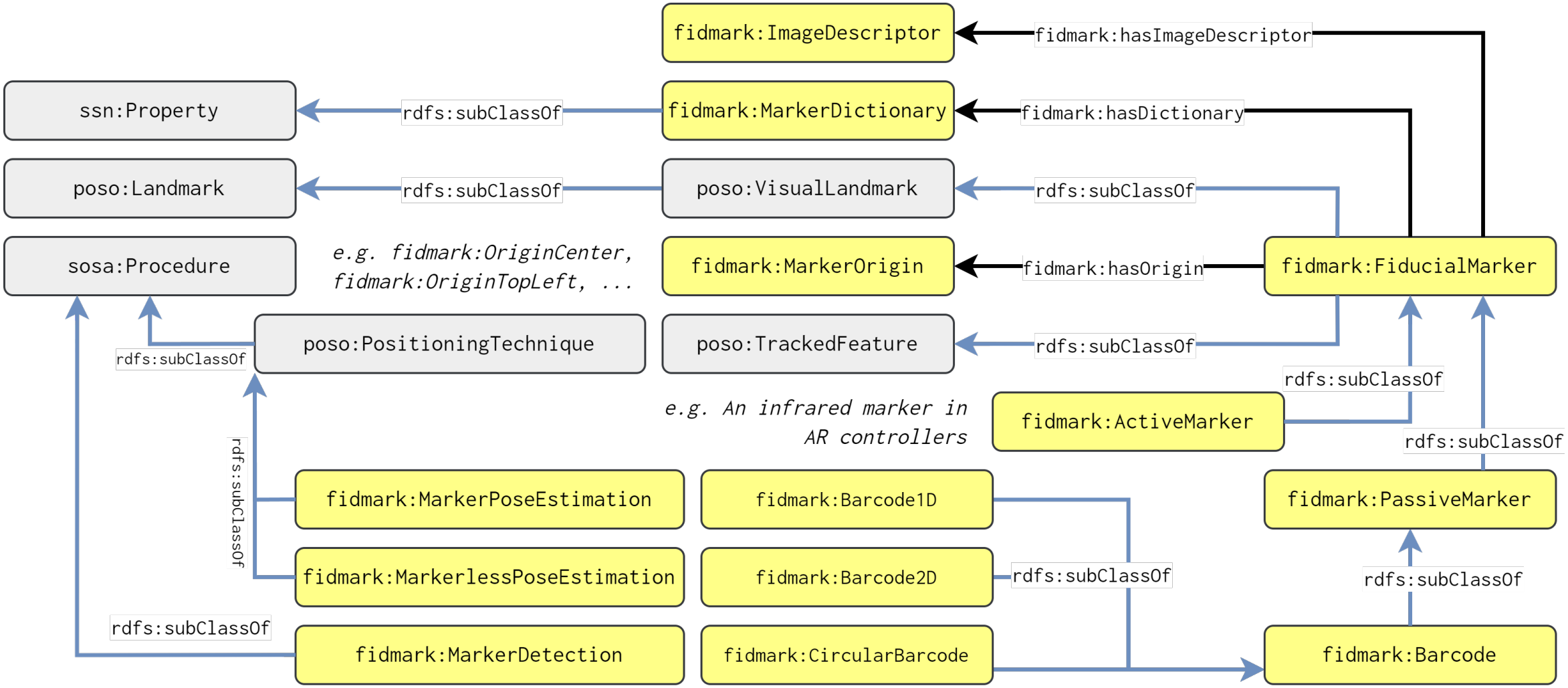
Based on the Linked Open Terms (LOT) methodology

Ontology Design

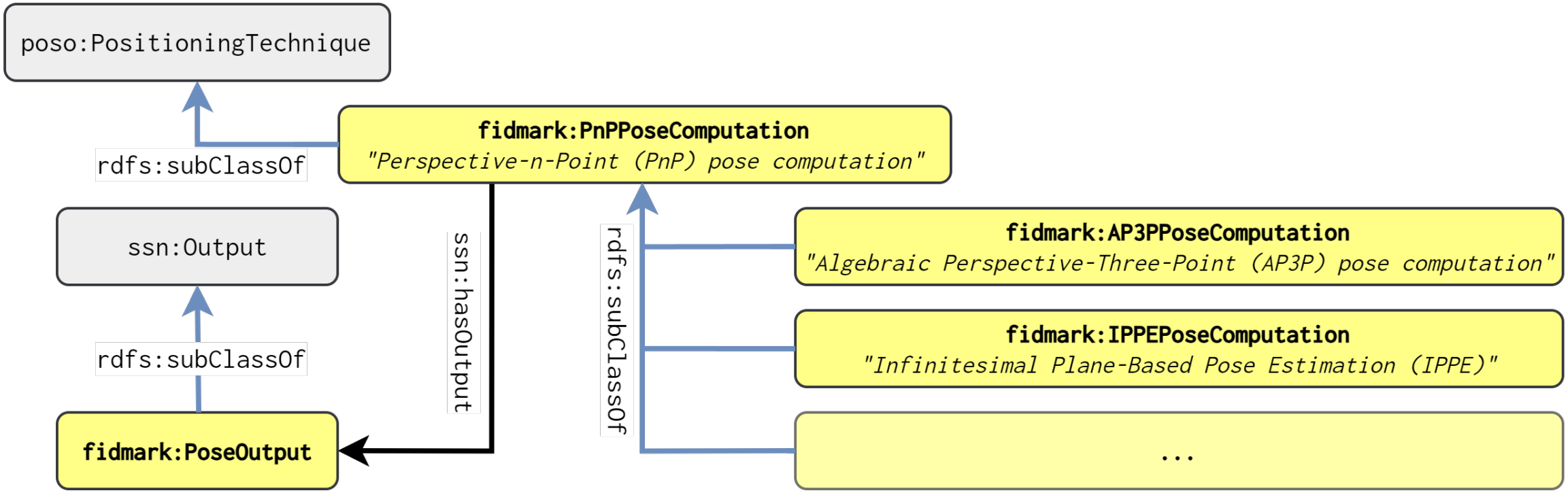


Maxim Van de Wynckel and Beat Signer. 2022. POSO: A Generic Positioning System Ontology. In The Semantic Web – ISWC 2022: 21st International Semantic Web Conference, Virtual Event, October 23–27, 2022, Proceedings. Springer-Verlag, Berlin, Heidelberg, 231–247.

Ontology Design



Ontology Design



Validation

- OOPS! Validator (OntOlogy Pitfall Scanner)
- Examples and generated dummy data
  - … random markers and virtual objects positioned relative to these markers
- SPARQL queries to answer design goals
- Demonstrator Web application
  - … and TypeScript library for implementing FidMark with js-aruco2, OpenHPS and Three.js

Validation – Example

```
:marker-1 a fidmark:ArUco ;
  fidmark:markerIdentifier 10 ;
  fidmark:hasOrigin fidmark:CenterOrigin ;
  fidmark:hasDictionary fidmark:DICT_MIP_36h12 ;
  fidmark:hasWidth [ a qudt:QuantityValue ;
    qudt:unit unit:MilliM ; qudt:numericValue "200"^^xsd:double ] ;
  fidmark:hasHeight [ a qudt:QuantityValue ;
    qudt:unit unit:MilliM ; qudt:numericValue "200"^^xsd:double ] .

:earth a sosa:FeatureOfInterest ;
  poso:hasPosition [ a poso:RelativePosition ;
    poso:isRelativeTo :marker-1 ;
    poso:xAxisValue [ ... ] ; poso:yAxisValue [ ... ] ;
    poso:zAxisValue [ a qudt:QuantityValue ;
      qudt:unit unit:CentiM ; qudt:numericValue "10"^^xsd:double ]] ;
  omg:hasGeometry [ a omg:Geometry;
    fog:asGltf ".../earth.gltf"^^xsd:anyURI ] .
```

Validation – SPARQL queries

Get the position and orientation of a detected marker (i.e. an ArUco marker with ID 19)

```
SELECT ?position ?orientation WHERE {
    ?markerType rdfs:subClassOf* fidmark:ArUco .
    ?marker a ?markerType .
    ?marker fidmark:identifier 19 .
    ?marker poso:hasPosition ?position .
    ?marker poso:hasOrientation ?orientation .
}
```

Validation – SPARQL queries

Get all virtual objects placed relative to a QR-code marker with the data 0x001122334455

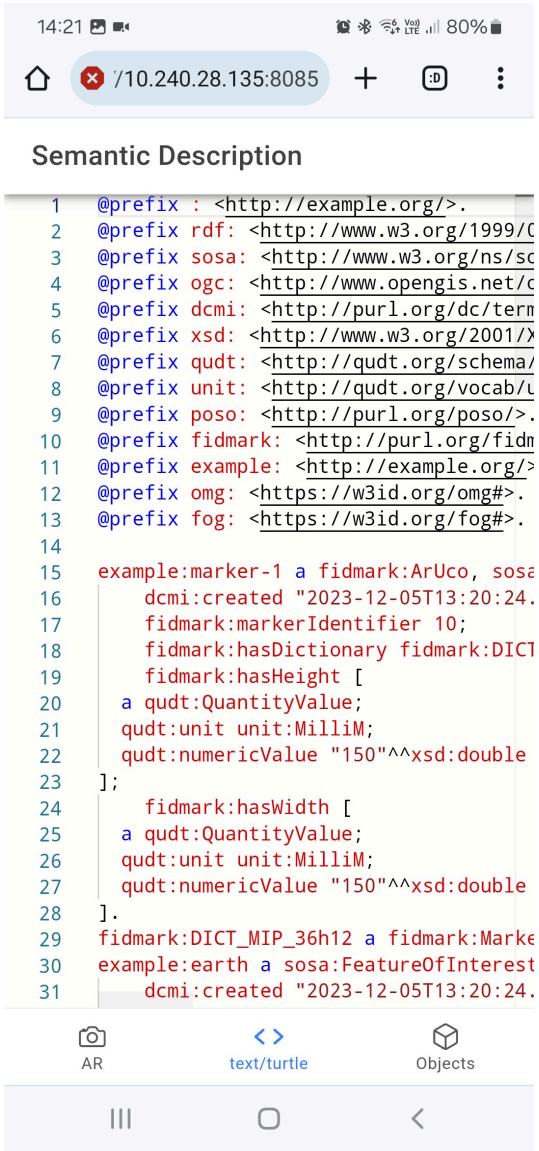
```
SELECT ?object WHERE {
    ?object a sosa:FeatureOfInterest .
    ?object omg:hasGeometry ?geometry .
    ?object poso:hasPosition ?position .
    ?position poso:isRelativeTo ?marker .
    ?marker a fidmark:QRCode .
    ?marker fidmark:markerData "001122334455"^^xsd:hexBinary .
}
```

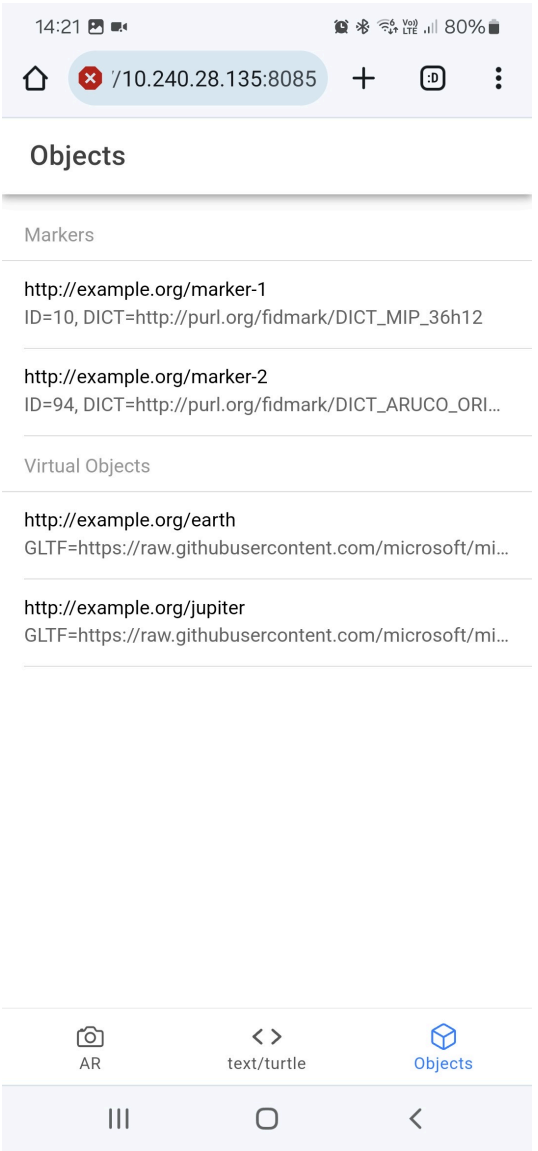
Validation – SPARQL queries

Find all dictionaries and the count of markers that can be identified in this dictionary for the marker type "TopoTag". Ensure that at least 150 markers can be identified.

```
SELECT ?dictionary ?size WHERE {
    ?dictionary a fidmark:MarkerDictionary .
    ?dictionary fidmark:supportedMarker fidmark:TopoTag .
    ?dictionary fidmark:dictionarySize ?size .
    FILTER(?size >= 150)
}
```

Demonstrator





Conclusions and Future Work

- Fiducial marker ontology with a **focus on Augmented Reality** and pose estimation
- **Extensible ontology** with support for future marker types and dictionaries
- **Demonstrator** application **&** TypeScript **library**
- Future work will add new marker types and SHACL shapes for each of these types

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https://purl.org/fidmark/

https://fidmark.openhps.org/

https://github.com/OpenHPS/FidMark/

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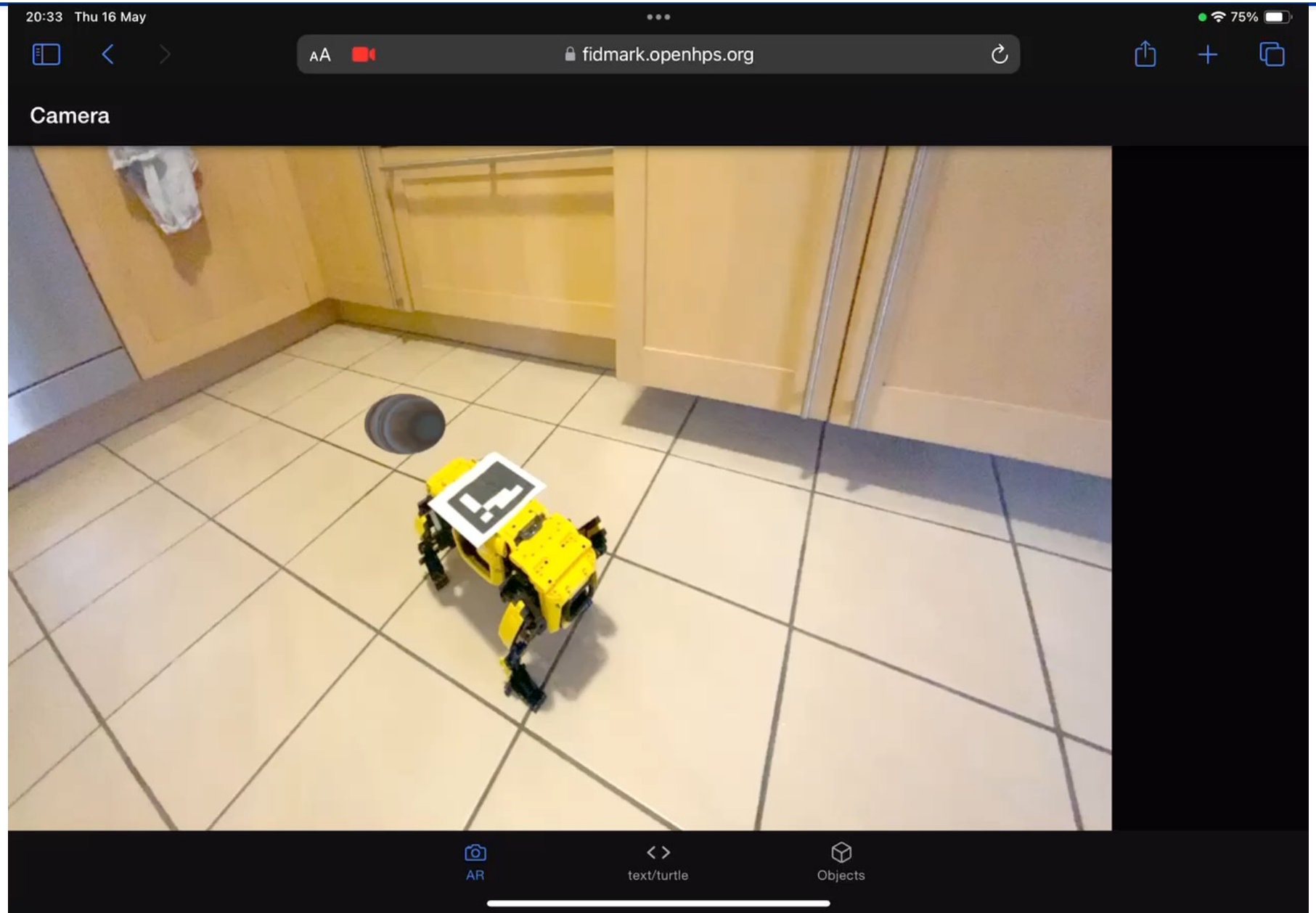
Methodology - Design Goals

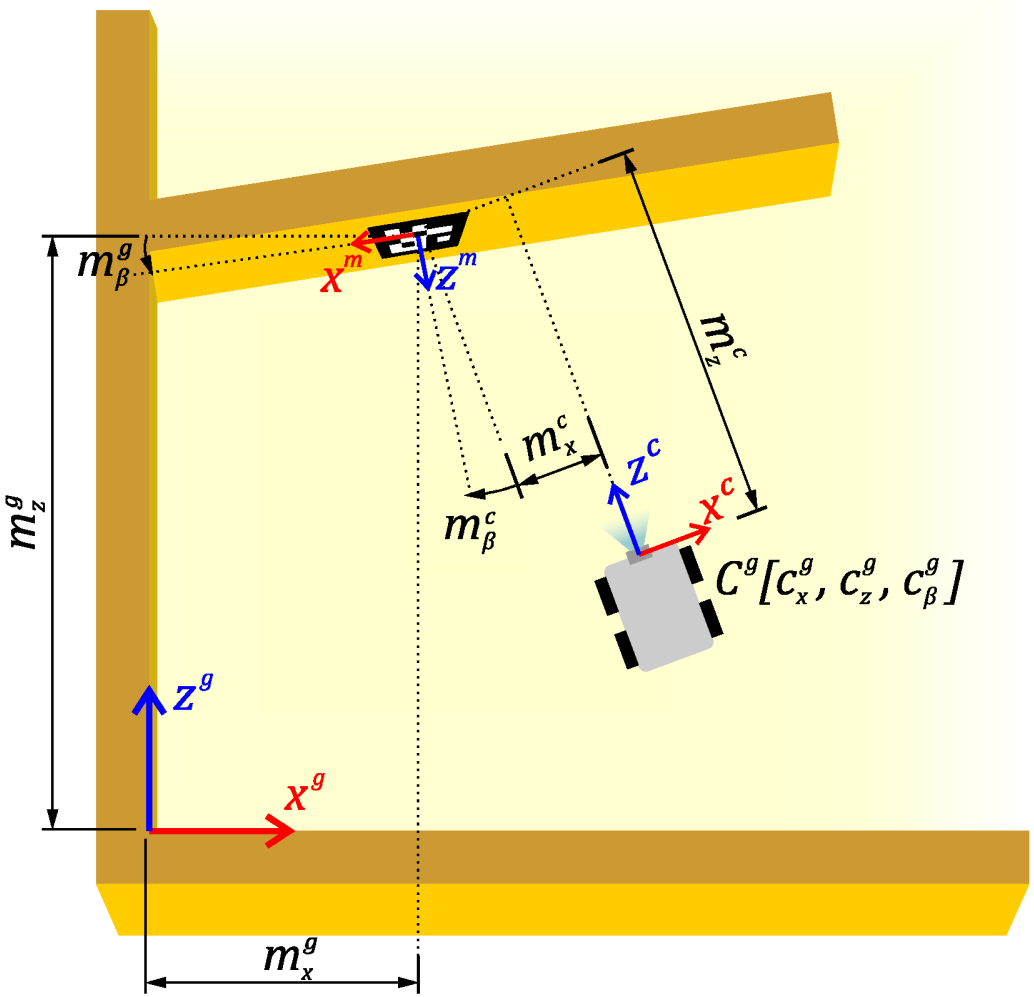
Central goal: "Interoperable Augmented Reality Applications"

DG1 Retrieve a list of supported markers
DG2 Retrieve markers using the identifiable information
DG3 Describe markers with a non-standard symbology
DG4 Enable pose estimation of markers
DG5 Enable relative positioning of objects to markers
DG6 Enable markers as engineering reference frames
DG7 Facilitate the integration in computer vision frameworks

Demonstrator



Background – Pose Estimation

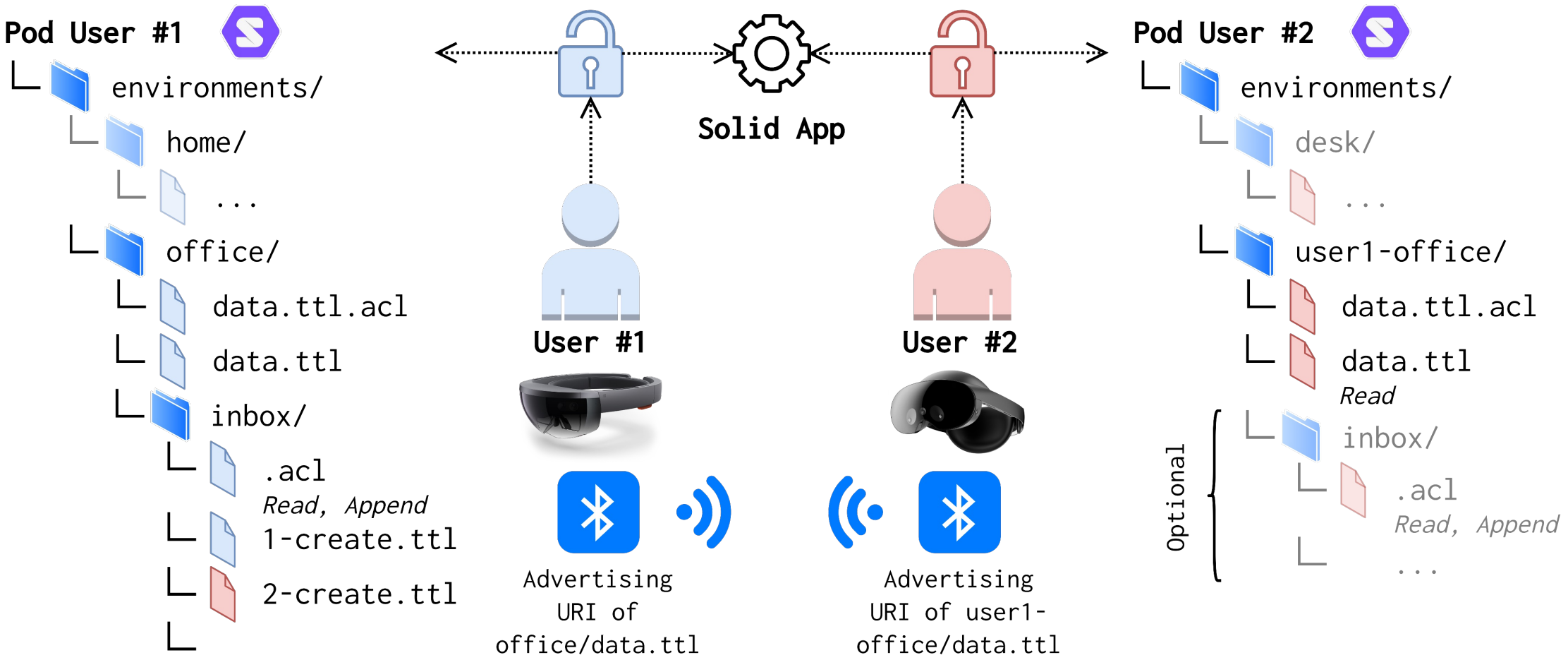


Adámek R, Brablc M, Vávra P, Dobossy B, Formánek M, Radil F. Analytical Models for Pose Estimate Variance of Planar Fiducial Markers for Mobile Robot Localisation. *Sensors*. 2023; 23(12):5746.

Validation – SPARQL queries

Select all square fiducial marker types

```
SELECT ?markerType WHERE {
    ?markerType rdfs:subClassOf* fidmark:FiducialMarker .
    ?markerType fidmark:shape "Square"@en .
}
```


Pod User #1
environments/
home/
...
office/
data.ttl.acl
data.ttl
inbox/
.acl
Read, Append
1-create.ttl
2-create.ttl
Solid App
User #1
User #2
Advertising URI of office/data.ttl
Advertising URI of user1-office/data.ttl
Pod User #2
environments/
desk/
...
user1-office/
data.ttl.acl
data.ttl
Read
Optional
inbox/
.acl
Read, Append
...

```
<> a seas:Room ; rdfs:label "Our Lab"@en ;
    ldp:inbox <./inbox/> ;
    vcard:address [ ... ] .
:table_marker a fidmark:AruCo ;
  poso:hasPosition [ poso:isRelativeTo <> ] ;
  fidmark:hasDictionary fidmark:DICT_ARUCO_ORIGINAL ;
  fidmark:markerIdentifier 94 ;
  fidmark:hasOrigin fidmark:OriginCenter ;
  fidmark:hasHeight [ a qudt:QuantityValue ;
      qudt:unit unit:MilliM ; qudt:numericValue "80"^^xsd:double
  ] ;
  fidmark:hasWidth [ a qudt:QuantityValue ;
      qudt:unit unit:MilliM ; qudt:numericValue "80"^^xsd:double
  ] .
```