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Quantitative Analysis of Coins as Size Reference

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***Abstract*—Coins are used for size comparison in photographs. This interdisciplinary study compiles a comprehensive dataset of over one thousand instances where coins are utilized as size references in scientific publications. Employing quantitative analysis, a numismatic measurement system is uncovered that's characterized by widespread adoption and discernible conventions governing coin use. The findings are presented in this article. The analysis reveals a prototypical numismatic measurement system with widespread use and distinguishable rules how coins get used. The prevalence of coins as a size reference is within the single-digit percentage range in several technical journals. Distributions examine the number of coins per article and explore correlations of coins by number of pages, figures and photos. Text analysis reveals the authors' deliberate choice to use coins for scale and size comparison.**

Coins lack many aspects of modern measurement tools. They are not used as a measurement unit unlike the meter or the inch and they don't provide a lower and upper bound on size. The dataset provides evidence that coins are used as size reference for objects with similar dimensions and are occasionally used in conjunction with other measurement tools. Coin properties other than their size are not widely used for measurement applications.

A numismatic analysis provides statistics of used currencies, denominations and mint years. Analysis reveals a trend towards larger currencies when using foreign coins, but generally coins are chosen from the first author's country. Similar items like banknotes, credit cards or jewelery are not used.

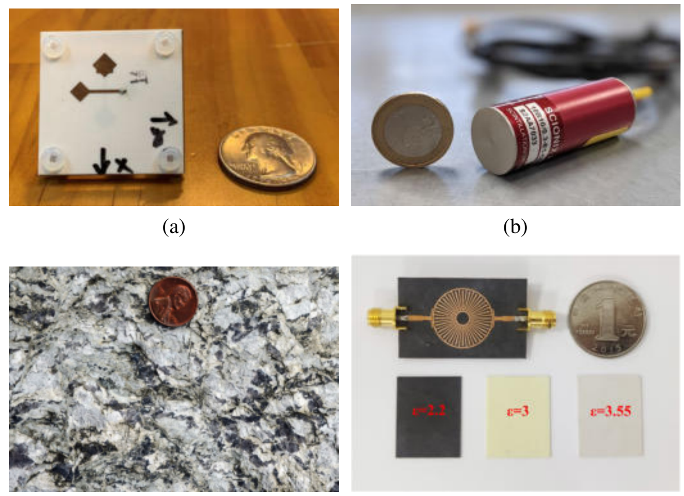
The investigation extends to the arrangement in scenes, whether they are placed next to objects or on them, the displayed sides and whether they are standing or lying horizontally. The study concludes by discussing notable outliers within the dataset.

***Index Terms*—Coin, comparison, data science, numismatics, dimension, measurement, scale, size, statistical analysis.**

I. Introduction

Perhaps due to boredom during the COVID-19 pandemic [1], I have decided to expand my previous work on the use of coins as a measure of size [2]. In case you aren't familiar with the method: People place coins next to other objects in photographs to provide a size comparison. Fig. 1 shows typical examples. In my previous work [2], I argued that coins not only provide an estimate of size, but also a true measurement of the object's size because the size of coins is standardized and widely known. This practice is also widely used among authors of scientific articles in peer-reviewed letters, magazines, and journal articles. I had collected over a hundred examples of coins used as a measure of size, analyzed them qualitatively, and identified rules on coin-based measurements, which are as follows:

1) Coins are used as a measure of size.
2) Usage of coins as measure of size is not explicitly stated.
3) Coins are not used as a measurement unit.



(a) (b) (c) (d)

Fig. 1. This work investigates coins that are used as size reference in photos. Some typical examples are shown above. a) Fig. 4 from [3], CC-BY 4.0, b) Fig. 1b from [4], CC-BY 4.0, c) Fig. 3b from [5], CC BY-NC 4.0, and d) Fig. 4 from [6], CC-BY.

4) Coins with a small monetary worth are chosen.
5) Coins are chosen from an author's country.
6) Coins are chosen from the first author's country.
7) Contemporary coins are used.
8) Coins are used as a measure of size only for coin-sized objects.
9) Coins are placed next to objects.
10) Coins are used as a measure of size only in photographs.
11) Coins are not used as lower and upper bounds of size.
12) Coin properties other than size are not used.
13) The displayed side of the coin is a currency-specific preference.
14) Representations of currencies other than coins are not used.

The statistical evaluation led to the formulation of five additional rules:

15) No objects similar to coins are used as size reference.
16) Coins are placed horizontally on the surface.
17) Coins are not combined with other measures of size.
18) Only one coin is used per photo.
19) If both sides of an object are shown, either the same coin side is displayed in each view, or only one view features a coin.

A. Contribution

This work expands the dataset from over a hundred to over a thousand scientific articles. The rules on coin use, which were formulated in [2], are analyzed quantitatively, and four additional rules are formulated and tested.

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B. Methodology

Over a thousand articles that use coins as size reference have been collected. Only scientific articles are selected for several reasons. Firstly, they are accessible since all are publicly available on the internet. Secondly, they are citable since articles found on the internet with unknown sources cannot be cited. Thirdly, scientific articles are usually available for at least several decades, and they might be expected to remain archived for a century. Fourthly, the coin depictions are objective, and fifthly, the scientific work provides context. Lastly, they are used by experts who are knowledgeable in measurement techniques, and it can be assumed that scientists have access to more precise tools to measure the size of objects. The coins are used with intent in the cited articles, they are never part of random clutter in the image background. Their placement is not accidental.

All articles are peer-reviewed which shows that there is a consensus between authors, reviewers and editors that coins are a good choice. To be considered as a scientific article for the purpose of this investigation, articles must be published in journals that are either listed in the Science Citation Index or in the Science Citation Index Expanded [7]. Examples are mainly collected from the field of electrical engineering, because this is both the author's field of interest and a large number of coins are used in this field. Over ten thousand articles were manually scanned to find examples. Articles were also found through online image searches by combining various terms similar to *coin + open access* or *coin + prototype*. Although some journals contain a large number of articles that use coins, no more than one hundred articles were collected from any single journal to ensure a diverse sample. All journal articles from [2] are included, while conference papers and books are omitted. Retracted articles are not included [8], neither are editorials, summaries [9] and white papers [10]. Coins appearing on journal covers, article cover pages, or advertising pages are also excluded [11]. Works where coins are the subject of the research are not included in the sample. This excludes all numismatics works, articles about manufacturing of coins [12], medical applications or remedies for coins [13], [14], coins used in chemical processes [11], [15], coins used to test measurement devices [16], and so on. In all cases it is clear from the context whether coins are used as size reference or part of the research, for example pictures of rocks and soil with coins are included when it is obvious that the coin was deliberately placed there, but excluded when the coins were found in an archeological dig.

The collected articles were analyzed and the data were stored in a spreadsheet. The dataset is available online [17]. Each individual coin depiction is a line (observation) in the spreadsheet. Some journals don't assign each photo to its own figure and some even include several photos under the same subfigure label. If the same coin is used multiple times within the same (sub)figure, then this leads to multiple identical entries in the data set. There are some outliers for which this procedure skews the statistical evaluation, for example [18] shows a photo series of a robot being maneuvered through rings. The article contains nine photos with coins in the same scenery in Fig. 4, nine more photos of a different scenery in Fig. 5 and one coin in a third scenery in Fig. 7. Whenever copies of photos in different articles were found only the older one was kept, this happened quite a lot in review articles and with famous photos (for example the photo of Leon Theremin's seal bug is used in several articles [19], [20]). However, given the large numbers of coins investigated in this work, it is likely that some duplicates were missed. There is also one curious case of a completely duplicated article [21], [22]. A detailed description of the dataset is given in Appendix A.

The statistical evaluation was done in R, and the R script is available online as supplementary material. This work investigates properties of the found coins and the articles in which they are placed, but there is some ambiguity. For example Euro coins have a distinct feature where the obverse is designed by the issuing country, but their reverses are identical. So when a photo only shows the reverse of a Euro coin, the countries and obverses are unknown. There is also some ambiguity in determining properties of articles, for example, when determining page numbers to calculate coins per page. Many journals have transitioned to an online-only format that no longer uses page numbers, and many now use HTML as the default way to view articles, which doesn't use pages. Some journals have introduced e-book reader versions of articles, have added cover sheets or advertising pages on portable document format (PDF) versions, or offer extended versions with more details than the print version. Additionally, articles often come in different version such as arXiv versions, preprints, author proofs, accepted versions, and versions with added comments or errata. For the samples to be comparable, the *standard PDF* version of each article was collected from the publishers website. A PDF version was available for all found scientific articles, and no articles had to be omitted from the sample for not having a PDF version. Advertising and cover pages were not considered to be part of the articles and were not counted towards article length.

II. Quantitative Analysis of Coins Used as Measure of Size

Let's start with some general statistics of the collected sample. I have collected 1104 articles from 191 different scientific journals. Fig. 2 shows how many articles were collected from each journal. The collected articles contain 1769 coins or an average 1.60 coins per article (since the collected articles contain at least one coin). Fig. 3 shows how many coins were drawn from each journal. I've systematically searched the journals Microwave and Optical Technology Letters, IEEE Transactions on Antennas and Propagation, and IEEE Antennas and Wireless Propagation Letters, and stopped after finding 100 articles per journal to prevent skewing the results too much towards a single journal. All articles the International Journal of Antennas and Propagation were systematically searched, and 93 articles with coins were found at the time of writing. I've also searched all article in Microsystems and Nanoengineering and found 41 articles with coins.

The systematically searched journals can provide an estimate on the percentage of articles that use coins. When all

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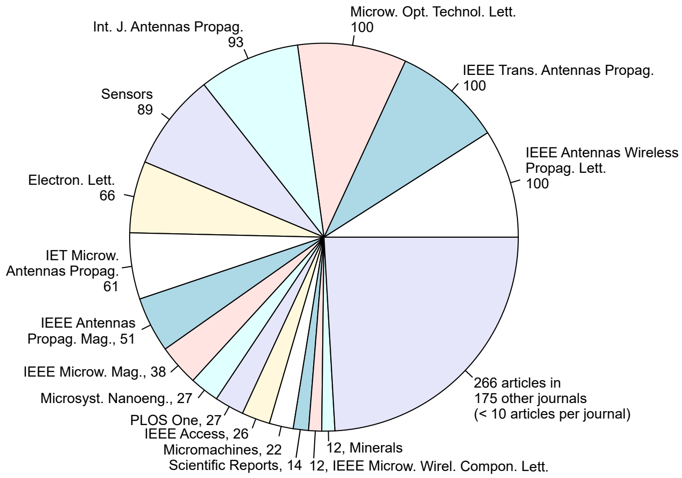

Fig. 2. Number of articles collected per journal. Total of 1104 articles from 191 journals.

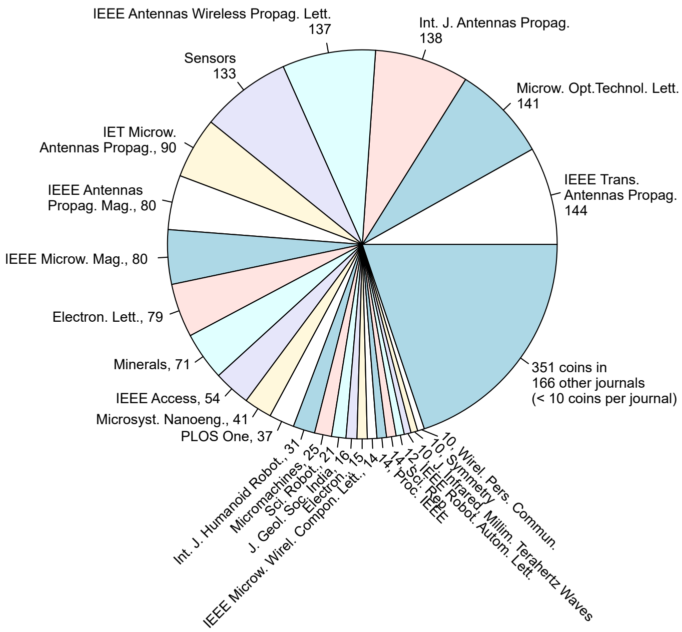

Fig. 3. Number of coins collected per journal. Total of 1769 coins from 191 journals.

articles with coins in a year are identified, they can be set in relation to the total number of citable documents from that year. Tab. I lists the percentage of articles that use coins as size reference. The number of citable documents per year were retrieved from Scopus. Scopus didn't list 2008 and 2009 data for *Int. J. Antennas Propag.*. I've searched *IEEE Trans. Ant. Propag.* and *Microw. Opt. Technol. Lett.* systematically, but I didn't write down the issues, so they are excluded here. The list only includes journals for which I've at least searched a full year. There are several journals where I've only searched a few issues, and stopped because of low yield. The classification of citable items listed by Scopus is blurry, for example category "review" might contain review articles, but also book reviews. I've included documents from the category articles and conference papers.

Fig. 4 shows the currencies in the collected sample. The

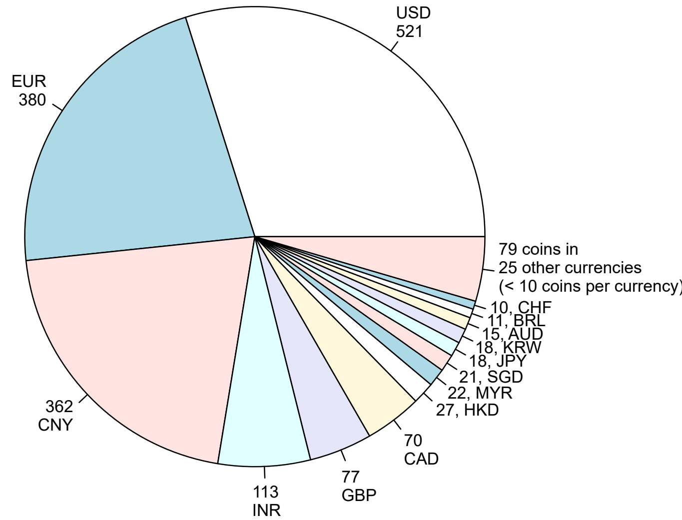

Fig. 4. Number of coins contained in the drawn sample by currency. Total of 1744 coins from 39 currencies. The currency of 25 coins couldn't be determined.

dominant currencies are USD, EUR and CNY, followed by INR, GBP and CAD. One currency is in the sample for which no country is found among all authors' affiliations: Four coins of the Omani rial (OMR) are used by authors from Japan [23]. On the flip side, there are 21 countries without corresponding coins in the sample: Algeria (DZD), Argentina (ARS), Bangladesh (BDT), Croatia (HRK), Hungary (HUF), Iceland (ISK), Indonesia (IDR), Iraq (IQD), Jordan (JOD), Kazakhstan (KZT), Kuwait (KWD), Lebanon (LBP), Macedonia (MKD), Peru (PEN), Romania (RON), Saudi Arabia (SAR), Serbia (RSD), South Sudan (SSP), Sudan (SDG), Ukraine (UAH) and Vietnam (VND).

Fig. 5 plots the distribution of the number of coins per article. Geology and robotics take the lead in most coins in a single article without much contest from other fields. Most articles (766 or 60.4 %) contain exactly one coin. Fig. 6 investigates the distribution of coins in articles further with different distributions of the number of coins in each article. At first glance they look of course similar because of the outliers, but when investigated in detail they reveal interesting insights. There are no articles in the sample that are only one page long. Most articles (91) are four pages long and have one coin. This is a typical case because the sample contains many articles from the field of antenna research. The four-page letter format is enough space to describe antenna design, manufacturing and measurements. These articles usually contain a photo of the prototype - and often a coin is used for size comparison.

The number of figures in articles can be counted, but Fig. 6b isn't too useful, because it is quite arbitrary how authors (or journal guidelines) distribute photos, images and plots into figures. Sometimes each photo gets its own figure and sometimes there are tens of images crammed into subplots. Although arbitrary, the number of figures can be determined easily (they are numbered) and it is objective.

Fig. 6c is probably the most interesting. There is a clear correlation between the number of photos and the number of coins in an article. Most articles (210) contain exactly one

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TABLE I
PERCENTAGE OF ARTICLES THAT USE COINS AS SIZE REFERENCE.

Journal	Year	Articles with Coins	Citable Items	%
IEEE Antennas Wireless Propag. Lett.	2016-2018	96	1855	5.2
Microsyst. Nanoeng.	2015-2019	20	222	9.0
Int. J. Antennas Propag.	2010-2021	87	2263	3.8
Electron. Lett.	2016-2021	61	3973	1.5
IET Microw. Antennas Propag.	2019-2021	55	832	6.6
IEEE Antennas Propag. Mag.	2006-2012	24	736	3.3
IEEE Electromagn. Compat. Mag.	2018-2020	2	106	1.9
IEEE Microw. Mag.	2014-2019	35	553	6.3
IEEE Trans. Electromagn. Compat.	2019	1	234	0.4
Science	2018-2019	4	1890	0.2

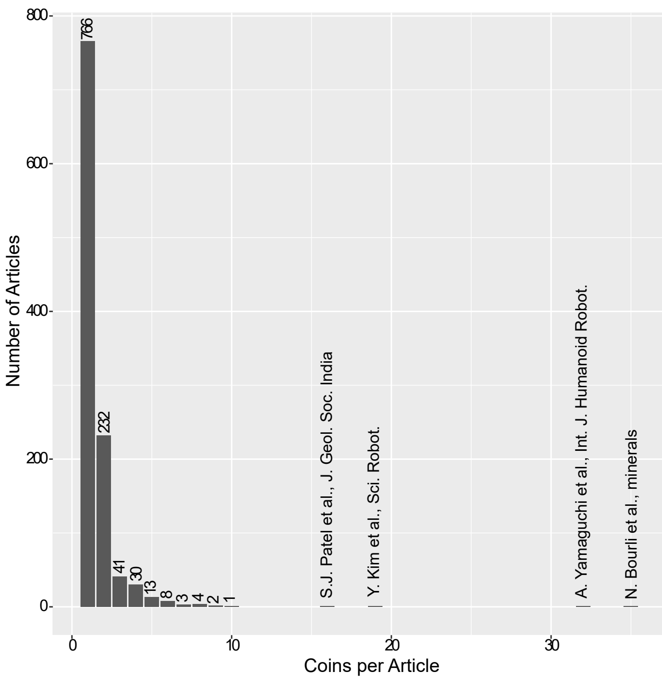


Fig. 5. Distribution of the number of coins per article. 60.4 % articles that contain at least one coin, contain exactly one coin. The outliers are [24] (16 coins), [18] (19 coins), [25] (32 coins) and [26] (35 coins).

photo and exactly one coin. Articles that contain no coins are of course excluded from the dataset. The next most likely case is that an article contains two photos and two coins (169 articles). A diagonal is visible which shows that many articles contain as many coins as they contain photos. There is also a horizontal line at the bottom: Articles that contain one coin independent of how many photos they contain. One outlier [27] contains a coin but contains no photo, this is because the coin is placed next to sketches of ticks. These correlations stem from the rule in Sec. III-J that coins are only used in photos.

III. Quantitative Investigation of Common Practices in Using Coins as Measure of Size

The large number of collected examples allows a statistical investigation of the rules that were formulated in [2]. The following subsections give quantitative investigations on how coins are used as size reference in scientific articles.

A. Coins are used as a measure of size

In most observations, identifiable coins are placed next to objects of well defined size (never next to liquids, gases or amorphous objects). Thirteen coins in five articles [25], [28]–[31] are placed next to piles. The five piles in [25, Fig. 10] consist of distinct objects with recognizable size so the coins measure both the pile size and the individual object sizes: Dried peas, rice, BBs (copper-coated bullets for toy guns), fusilli pasta and paperclips. [29] uses two coins next to piles of rubber powder in Figs. 1 and 2. [31] show four pavement samples with different gradations.

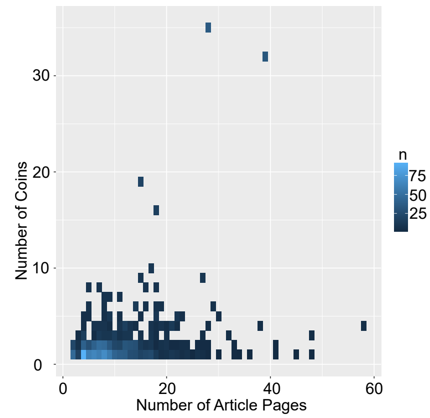
But then, there are two examples where powders are too fine and the coins fail to measure their size. [28, Fig. 4] compares a piece of polymer–ZnO nanostructure to a one Euro coin. The coin is too large to provide a comparative size to the nanostructure, and the material piece is later shoved into a glass tube (shown in the same subfigure). [30, Fig. 1] compares a one Yuan coin to a pile of seashell powder. The coins could serve as size reference of the nanostructure and the seashell piles, but the pile sizes don't seem to be relevant in these works.

There are 25 samples where the currency couldn't be uniquely identified, and 101 samples where the denomination couldn't be determined. This is mostly because of poor image quality or a combination of poor image quality and a currency where several denominations use the same images on one side, but the value is shown on the other side. I have argued in [2] that unidentifiable coins don't really serve as measure of size in such cases, but the authors' intentions were obvious in all examples as the coins were deliberately placed in these scenes. The measurement tool aspect was likely later lost because of technical constraints such as image resolution limitations.

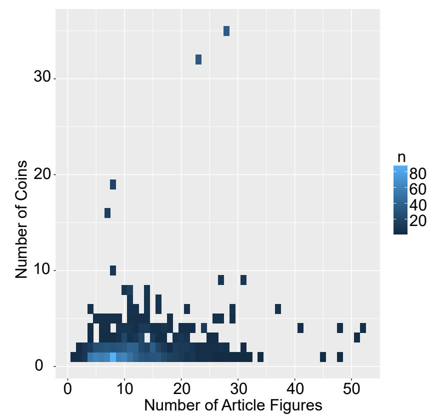
The authors' motives (see rule B) is to use coins as size reference or size comparison as most coins are of roughly the same size—"coin-sized". It can of course be argued that specific coins have a well defined size and their use is therefore a measurement [2], but this is clearly not the intention of the researchers who use coins in their photos. The rule could be formulated as: "Coins are used as measure of size, but it's their users intention to use them as size reference."

B. Usage of coins as measure of size is not explicitly stated

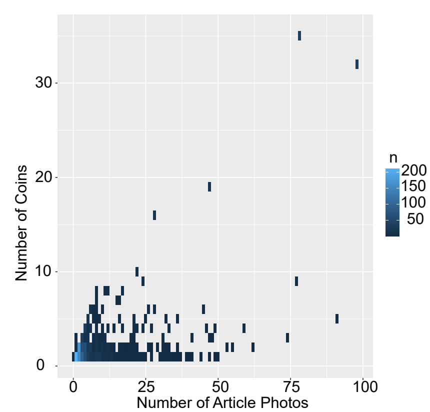
353 out of the 1416 coins are explicitly stated. this means that 24.9 % of coins or roughly every fourth coin is stated, which in the author's opinion, is too much to support the



(a)



(b)



(c)

Fig. 6. Distributions of number of coins in each article by a) the number of pages the article is long, b) the number of figures in the article (though it is quite arbitrary how articles combine photos, images and plots into figures and subfigures) and c) the number of photos in the article.

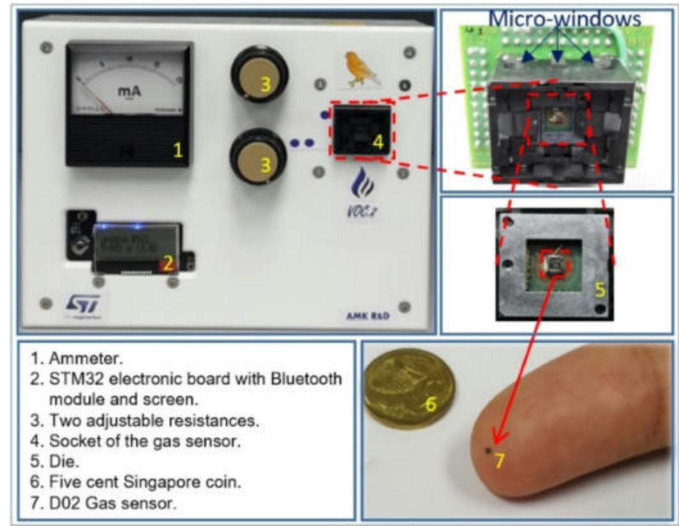


Fig. 7. The only found example in which the coin use is stated in the figure, but not in the photo with the coin. Image reproduced from Fig. 13 in [33], CC-BY 4.0.

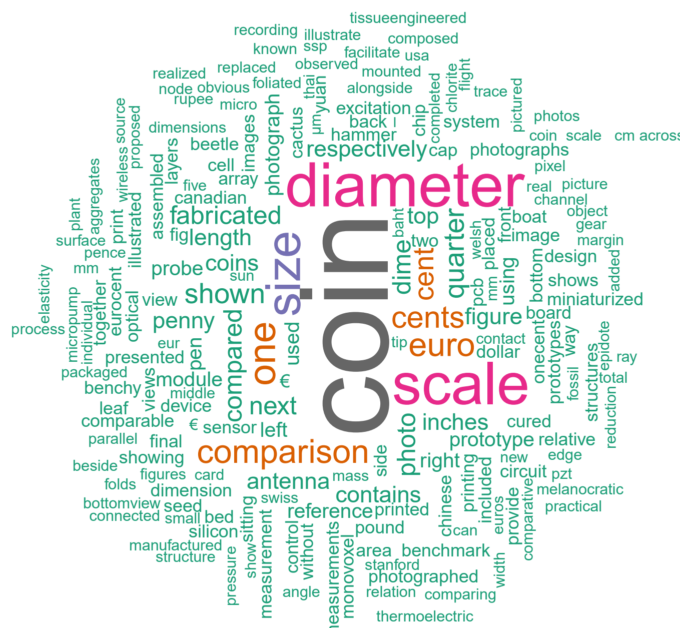


Fig. 8. Text cloud of the most common words used in images, captions and text to refer to the use of coins.

statement that coins are generally not stated. Out of the 353 coins that are explicitly stated, most (312) are stated only in the caption followed by being stated only in the text (21), plus nine times stated in both caption and text. Eight times coins were stated in the photo, one time in the photo and the caption. In [32] the coin use is stated in the photo, the caption and the text as "People's Bank of China (1 dime)", "Micro-pump compared with a coin." and "The size of the micro-pump is compared with a coin in Figure 5.", respectively. In one case the coin use was stated in the figure, but not in the photo itself, but in a separate table inside the figure [33]. That figure is reproduced in Fig. 7.

A textual analysis is given in Fig. 8 that shows the most frequent words used to refer to the coins. The cloud reveals that the text is typically used to state the diameter and currency and that the authors' intention is to provide a comparison of the size and the scale of the object. It is also used to name the coin, like *dime*, *cent* or *quarter*. The smaller words reveal the variety of applications in which coins are usually used for scale comparison.

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(a) (b)

Fig. 9. a) Coins are used as a measurement unit in [34] in the sense that multiples of a base unit are used. Three coins are stacked to measure the height as $3 \cdot \text{thickness}\,(5\ \text{INR})$. Copyright © 2019, IEEE. b) Coins are used as a measurement unit in [35] in the sense that fractions of a base unit are used, image used with permission.

C. Coins are not used as a measurement unit

The collected data show that this rule is overwhelmingly correct. Only six coins in three articles are used as measurement unit [34]–[36]. The combined thickness of tree stacked 5 INR coins are used to measure the height of a dielectric resonator antenna [34]. This is an example of a measurement where a height is measured in multiples of a base unit: $3 \cdot \text{thickness}\,(5\ \text{INR})$. The photo is reproduced in Fig. 9a. Fig. 9b shows an example where the diameter of a device is measured by using fractions of a base unit (0.1 USD) [35].

In [36] the coin is used as a measurement unit only in the text. Fig. 11 in [36] contains one coin and mentions it in the caption as "Implemented circuit board and size comparison with a coin," but only measures the device size as *two coins* (1 CNY) in the text on page 13: "The device is as small as the size of two coins and can be fixed on the wrist without external equipment."

D. Coins with a small monetary worth are chosen

Fig. 10 shows the distributions of denominations by currency. In all major currencies, except for the USD, the coin with unit value is the most popular. However, the lack of 0.5 and 1 USD coins isn't surprising. One dollar coins are notoriously unpopular in the United States. The United States Mint has barely produced them for circulation since 2012 and at several time intervals stopped producing them at all for decades [37][1]. The same is true for the Kennedy half dollar that has been barely produced for circulation since 2001.

It must be mentioned that a large number of 25 coins of the pound sterling could not be uniquely identified. All found coins depict Elizabeth II and if the image is of poor quality it is difficult to identify them. This might overemphasize the one pound coin in Fig. 10e. It is easy to identify these bimetal dodecagonal coins—even in poor-quality images.

There is a small number of circulating commemorative coins in the sample. The following coins from the United States 50 State Quarters program (one each): Hawaii, Kentucky, Michigan and New Hampshire. There are also five Bicentennial quarters (0.25 USD) and one Presidential Dollar showing James K. Polk. From Canada: Dance of The Spirits (non-colored, 2 CAD), Knowledge Le Savoir (2 CAD) and Remembrance Day (0.25 CAD). One circulating commemorative coin from Egypt is included: National Roads Network (1 EGP). These circulating commemorative coins are minted for circulation. They are not collectors coins and it is common to get them as change and to carry them in wallets.

[1]The numbers are available publicly on the website of the United States Mint, but they are difficult to cite because the URLs change. Citable documents mostly focus on a given year. The Wikipedia article presents the consolidated data.

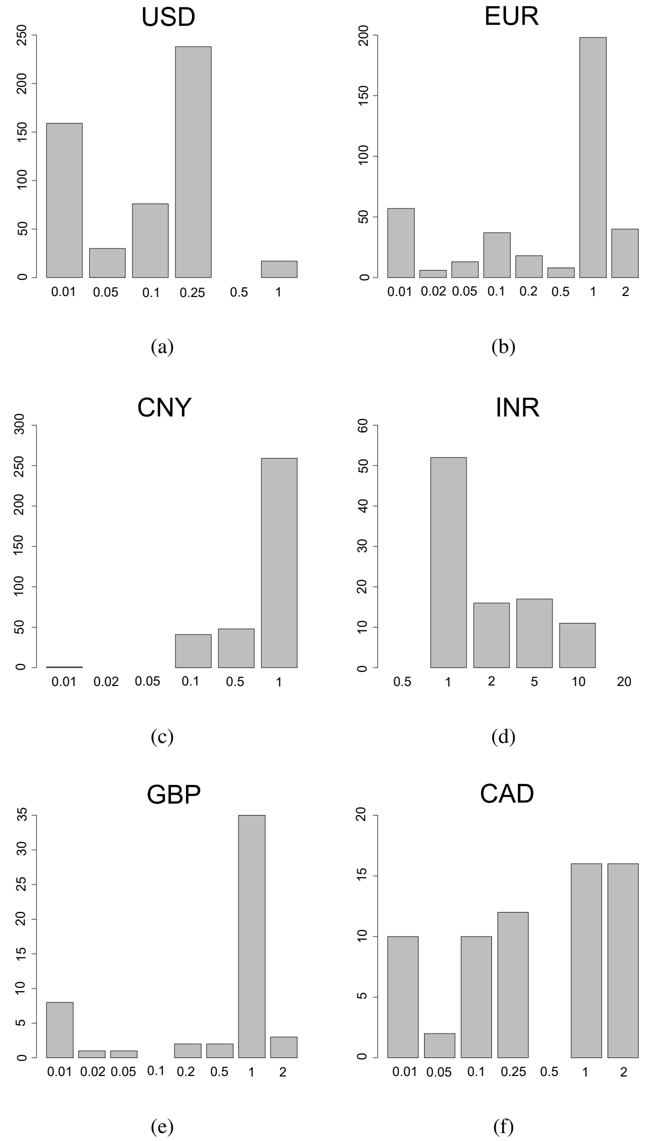

Fig. 10. Distributions of denominations by currency a) United States dollar (USD), b) euro (EUR), c) Chinese yuan (CNY), d) Indian rupee (INR), e) British pound (GBP) and f) Canadian dollar (CAD).

[38] uses two deep cameo USD penny proofs (2018, mint mark S) with a frosted finish and a mirror-like appearance of the background. Otherwise, non-circulating commemorative coins were not found. Bullion coins are also not used. Overall, the term "circulation coins" provides the most accurate description of the used coins.

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E. Coins are chosen from an author's country

1438 of 1743 coins (82.6 %) in the sample are selected from an authors' country (not considering 25 coins for which the currency couldn't be determined and not considering [39] in which no author affiliations are given). The countries are the ones given in the article as affiliation by the authors themselves.

It is worth mentioning that there are likely ambiguities and errors in the underlying data. For example in two articles published by the same three authors in the same journal in the same year [40] and [41], the affilation is given as "College of Electronic Science and Engineering, Nanjing University of Posts and Telecommunications, Nanjing 210003, China" in one article and as "Indian Institute of Technology Roorkee, Electronics & Communication Engineering, IRDSP Lab, Roorkee, India 247667" in the other, respectively.

Fig. 11 shows the flow of foreign coins [42]. On the left are the affiliations of the authors and on the right are the currencies of the used coins. The affiliated countries are those given by the authors in the articles (renamed to common country names). If a coin is from a currency of at least one author's country then the coin is not considered, for example if authors from China and Austria use a Euro coin then no China-to-EUR link is considered for the purpose of this graph. Coins where the currency couldn't be determined were removed as was one article where the authors' affiliations couldn't be determined [39].

The data show a general trend towards large currencies. The intention might be to use a more widely recognized coin, as opposed to showcasing rare currencies. The US Dollar is the most favorite foreign currency for coins to use as size reference, followed by the Euro. Authors from Taiwan use only USD as foreign coins. Among the smaller currencies the Hong Kong Dollar is noteworthy which is especially popular among Indian authors.

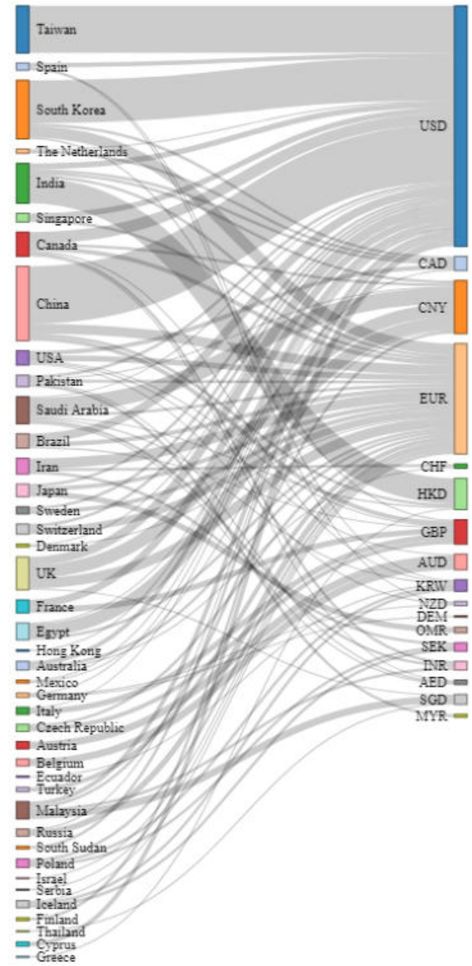

Fig. 11. Foreign coins used: Currencies by any authors' affiliations for coins where none of the author affiliations matches the currency. Note that several countries can be linked to one coin as it is not unusual that the authors are affiliated with several countries.

F. Coins are chosen from the first author's country

1372 of 1743 coins (78.7 %) in the sample are selected from the first author's country or countries (not considering 25 coins for which the currency couldn't be determined and not considering [39] in which no author affiliations are given). The countries are the ones given in the article as affiliation of the first author. Some journals consider several "first authors" for a work, but this is not considered in this evaluation.

Fig. 12 shows the flow of coins that are foreign to the first authors of articles. On the left are the affiliations of the first authors and on the right are the currencies of the used coins. The affiliated countries are those given by the first authors in the articles (renamed to common country names). Note that several countries can be linked to one coin as it is uncommon that first authors are affiliated with several countries. If a coin is from a currency of at least one first author's country then the coin is not considered, for example if the first author is affiliated with both China and Austria and they use a Euro coin then no China-to-EUR link is considered for the purpose of this graph. Coins where the currency couldn't be determined were removed as was one article where the first author's affiliations couldn't be determined [39]. Overall, the evaluation based on first author affiliations is quite similar to the evaluation based on all authors in Fig. 11. Nonetheless, the first-author formulation is simpler and falsifiable to a higher degree than the previous one and the difference between first authors country (78.7 %) and any authors country (82.6 %) is small.

G. Contemporary coins are used

Investigation of the shown years on coins reveals that old coins are sometimes used, but from currencies that are still in use at the time of publication. The largest difference are the five images of US quarters from 1943 used in an article published in 2017 [43], followed by a 1945 coin published in 2014 [44]. The USD quarter and 3-cent violet Win the War stamp were excellent choices by the MTT-S Historian for the article [43] and the coin is also the oldest in the sample (by visible year in the photo). Only one coin was used from a currency that was no longer in use in that country at the time of publication. Authors in [45] used a one Deutsche Mark (DEM) coin in 2007, five years after the switch to Euro coins in Germany.

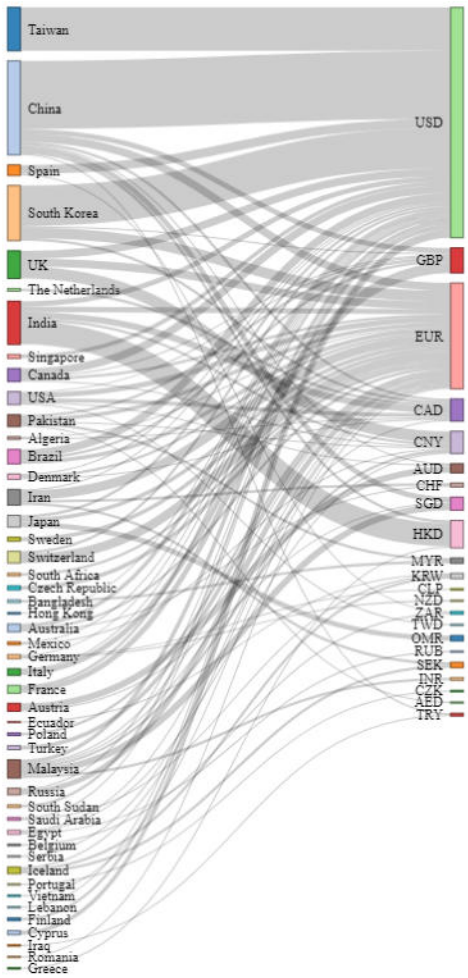

Fig. 12. Foreign coins used by first authors: Currencies by first author's affiliations for coins where none of the first author affiliations matches the currency. Note that several countries can be linked to one coin as it is uncommon that first authors are affiliated with several countries.

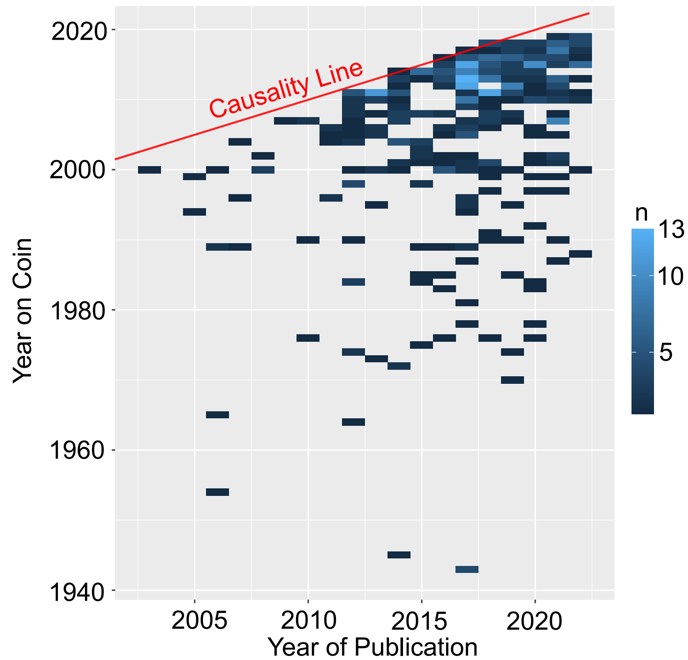

Fig. 13. Year of the article publication vs. the year shown on coins. The coloring represent the number of coins n.

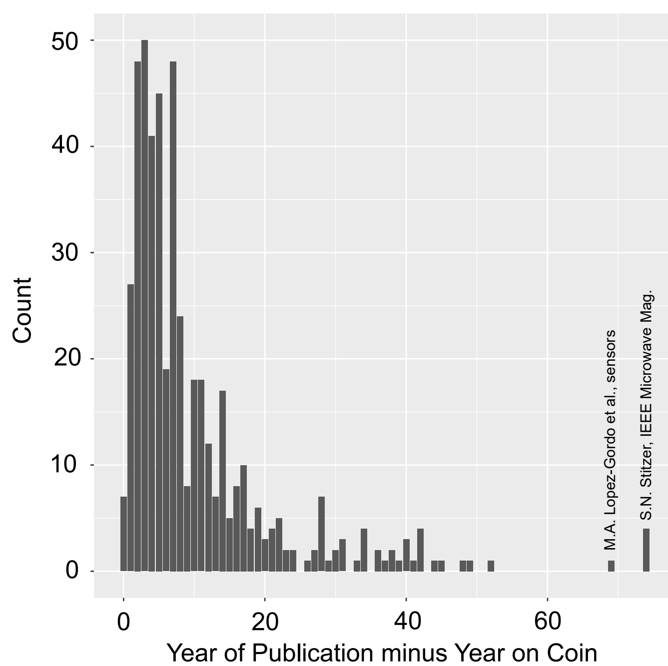

Fig. 14. The distribution of year of article publication minus the year shown on coins. The outliers are 69 years [44] and 74 years [43] difference between coin issue and publication of the article.

A plot of the year of publication vs. the year on the coin is shown in Fig. 13. Note that the underlying data are biased. The year is often not visible on older publications because of the poorer photograph and printing quality at the time. The year of issue is typically only shown on one side. The year of issue is unknown if the other side is visible in a photo. For currencies (like EUR, see Sec. III-M) where the side without year is predominantly shown then consequently many of them are missing here. The year is known of 52,2 % CNY, 23.2 % USD, but only 0.79 % EUR coins.

Fig. 14 plots the distribution of the years articles were published minus the year written on the coins. The relationship is causal: There are no coins on which the year is greater than the year in which the article was published. There is also a delay between the year on coins and publication, which isn't surprising, because it takes a long time from preparing a manuscript until publication.

Generally the statement holds: Contemporary coins are used. All coins in the sample could be in circulation at the time of writing or publication and no truly historic coins were found. For example the sample contains no Roman sesterces and no proto-money.

H. Coins are used as a measure of size only for coin-sized objects

Coins are generally of a similar size as the object that they are compared to. They are never compared to cars or buildings and on the other end of spectrum they are not compared to nano-structures or used under microscopes. The size of coins

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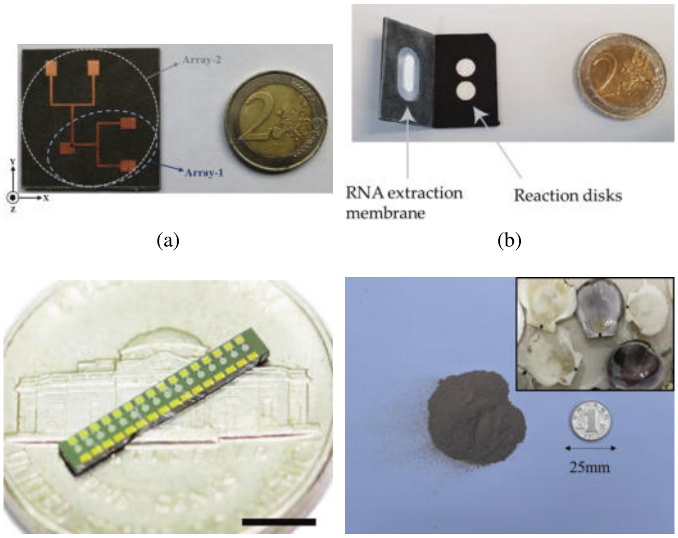


Fig. 15. Coins sizes relative to the objects that they are compared to. a) 1235 coins (69.9 %) are smaller than the object. Example: Fig. 2a from [46], CC-BY 4.0, b) 297 coins (16.8 %) are classified as being the same size as the object. Example: Fig. 1A from [47], CC-BY 4.0, c) 220 coins (12.5 %) are larger than the object. Example: Fig. 3c from [48], CC-BY 4.0, and d) 13 coins (0.7 %) are next to piles which are classified as their own special case. Example: Fig. 1 from [30], CC-BY 4.0.

relative to their objects has been quantized for the collected sample. Examples are shown in Fig. 15. Most coins (1235, 69.9 %) are smaller, 297 coins (16.8 %) are about the same size and 220 coins (12.5 %) are larger than the object.

Piles got their own category although the use with piles is quite rare (13 coins, 0.7 %). In all found instances, the individual pile elements are smaller than the coin—and sometimes by a lot—while the piles themselves are larger than the coins. Piles are such a curious case, because it isn't clear what is being measured. For example, the pile in Fig. 15d shows powdered seashells, but the seashell powder is quite small to be compared to the coin. The sizes of piles in the photos are mostly arbitrary and aren't relevant to the scientific works.

I. *Coins are placed next to objects*

Coins are always placed in the vicinity of the shown objects to prevent perspective distortion of size. This rule investigates where coins are placed in scenes relative to objects. It is fair to talk of scenes as there is always a presentation of objects in these photos and some degree of composition and arrangement of the objects. The different placement positions were categorized as is shown on the example of a shot glass in Fig. 16. The vast majority of 1349 coins (76.3 %) are placed next to their object. 266 (15.0 %) coins that are placed on objects. Placing coins under (79, 4.5 %) or in front (63, 3.6 %) of objects is uncommon and placing coins in or behind objects is rare (both 5, 0.3 %). Of the 266 coins that are placed on objects, 100 coins are placed on less important parts of the object. What is meant by unimportant parts? Many articles are taken from antennas and electronics research where structures are often built on substrates such as printed circuit boards. While they can be considered to be part of the shown objects,

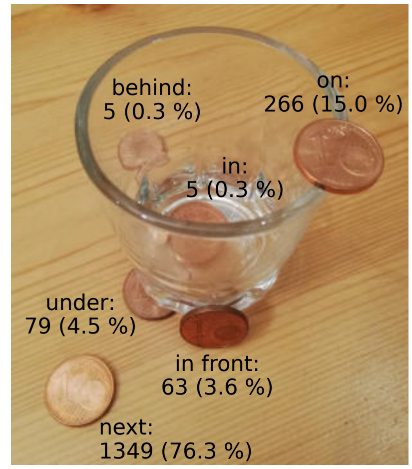


Fig. 16. Categorization of coin placement in relation to objects. Euro cent coins are exemplarily placed around a shot glass.

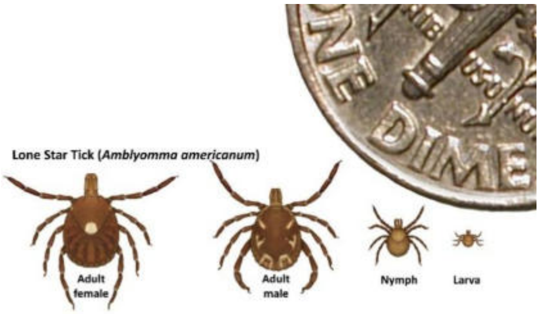
it is often clear from context that they are not the primary focus of the work. Placing coins on these less important parts fulfills more or less the same function as placing the coin next to the whole object as the coin doesn't obscure important features. However, without being knowledgeable in a field, it is difficult to identify which parts of an object are important or not (for example, I couldn't identify the important features of rocks), so the *unimportant parts* focus mainly on works on electric engineering.

J. *Coins are used as measure of size in photographs and only in photographs*

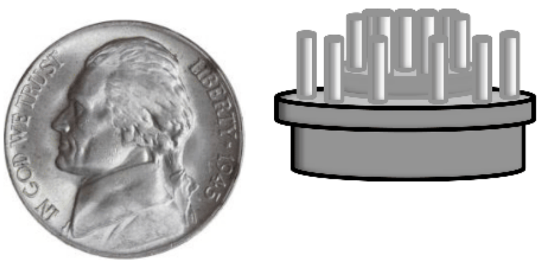
The collected data show that coins are generally only used as size reference for objects in photographs, for example the dataset contains no coins used in oil paintings. The dataset contains only two examples where photos of coins are not used with object photographs [27], [44], both are shown in Fig. 17. [27] uses a coin photo next to sketches of ticks. The coin in [44] is placed next to a sketch of an ambulatory wireless EEG system. The work is cited from [49] in which also a Jefferson Nickel (0.05 USD) is used, but with a photo of the sketched system and the nickel in [49] is from 1995 whereas the nickel in from [44] is from 1945.

[25] contains around 100 photos, 32 of which contain coins. Each time a quarter USD is used for a different object, except in one image in which the diameter of a US quarter is provided. That image also appears to be a promotional depiction of the coin and not an actual photo taken by the authors.

A surprisingly large number of articles were found where the coin was a separate image [50]–[62]. Sometimes this happens because the styles of certain magazines place figures in colored boxed and backgrounds are removed, thus the coin and the device become separated [63]–[68]. Further examples show evidence of image editing such as image-compression artifacts, irregularities in the background or shadows pointing in different directions [69]–[75]. They hint that object and coin were different images that were later merged. In a few cases promotional image of coins are used [25], [76], [77].



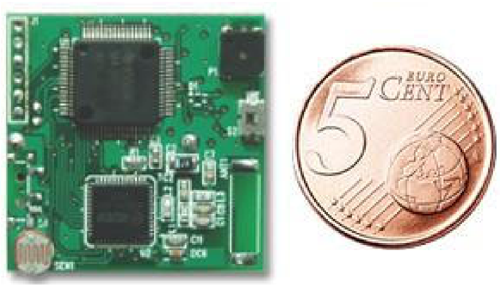
(a)



(b)

Fig. 17. Examples of coins not used in photographs. a) A photo of a coin is used with sketches of ticks. Image used with permission from Fig. 3 in [27], CC-BY 4.0. b) A coin photo used with a sketch of an ambulatory wireless EEG system. Image used with permission from Fig. 3a in [44], CC-BY 3.0.

(a)



(b)

Fig. 18. a) Example of a coin that is placed as a separate photo. Note how the coin diameter is given in millimeters, but the size of the mmWave antenna modules is not provided. Used with permission from Fig. 4 in [59], CC-BY 4.0. b) Example of a promotional coin image used in an article, used with permission from Fig. 5 in [77], CC-BY 3.0. Wikipedia lists the European Central Bank as image source of the 0.05 EUR image.

Otherwise the coin depictions are exclusively photos and no other artistic methods like paintings or AI generated coins [78] were observed. Examples are shown in Fig. 18.

K. Coins are not used as lower and upper bound of size

Measurement results are not only a single number. A measuring device can only determine a physical property within its accuracy and modern measurement systems also characterize the uncertainty of the result. Measurement uncertainty might be quantified by giving a standard deviation or by providing lower and upper bounds. For example, one might use a ruler to determine that the length of an object is larger than 1 cm, but shorter than 2 cm. In practise, there won't be many objects that (coincidentally) have the exact same size of a coin, or a coin with the exact size of an object might not be available. Like markings on rulers, coins of different size could be used to provide a lower and upper bound of an object's size. The dataset was searched for instances where coins are used as bounds for objects size and other ways that quantify measurement uncertainty.

Fig. 19. Noimanee et al. use different Thai bath (THB) coins. Do they act as both lower and upper bound to measure size? Fig. 2 from [79], ©2007 by MDPI (http://www.mdpi.org). Reproduction is permitted for noncommercial purposes.

Only a single article was found which uses coins as both lower and upper bound of size. Noimanee et al. use two Thai bath (THB) coins to measure the size of three different objects [79]. The photo is reproduced in Fig. 19. The use as lower and upper bound is likely accidental and unintended by the authors as not all objects in the scene have smaller and larger coins. Generally the rule holds and coins are not used as both lower and upper bounds of size.

L. Coin properties other than size are not used

The rule holds, but it should be formulated more precisely. The focus of [2] was the use of coins in measurement applications. A more precise formulation might be: Of all physical properties of coins, only their size is used for measurement (or reference) purposes in scientific articles.

The drawn sample contains a single scientific article in which a coin is used both as a size reference and for another purpose [80]. Grosinger *et al.* use three coins in their article, always as size reference for Radio Frequency Identification (RFID) tags and readers coils. In two images they use one Euro cent coins in the usual way: lying next to the objects with the reverse up. In the third image, they've soldered a two Euro cent to the outer conducted of an Subminiature Version A (SMA) connector. They use the coin's electric conductivity and plane surface as electrode to form a capacitive link to the tag, see Fig. 20. The Austrian coin shows the Edelweiß (Leontopodium nivale) on the obverse.

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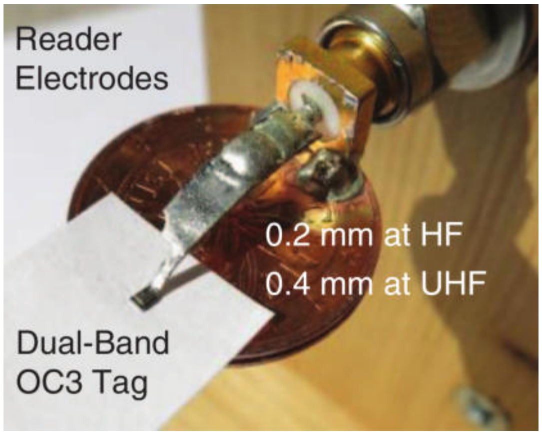

Fig. 20. Grosinger et al. use coins both as measure of size and as an electrode in an RFID reader. Fig. 2c from [80]. Copyright © 2018, IEEE.

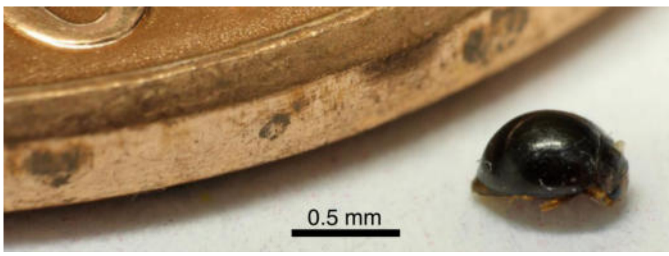

Fig. 21. An example where the photo mainly shows the coin edge. The majority (99 %) of photos focus on the obverse or reverse. Fig. 1A from [82], reused with permission.

Surprisingly, I've found only a single article during my research, in which a coin is used to measure monetary value. In [81] a penny is used next to a 3D-printed device in Fig. 1d and the text on page 6 reads: "On a cost-per-weight basis, the material cost of manufacturing one device is approximately \$0.01, enabling economic production of many devices." So the penny is not only used as size reference, but also as monetary reference for the production cost of the device.

M. The displayed side of the coin is a currency specific preference

TABLE II
PRIMARILY SHOWN SIDE OF THE COIN.

Dataset	Obverse	Reverse	Edge
All	626 (36 %)	1102 (63 %)	10 (1 %)
USD	350 (67 %)	168 (32 %)	2 (0 %)
EUR	23 (6 %)	255 (94 %)	0 (0 %)
CNY	75 (21 %)	286 (79 %)	1 (0 %)
INR	23 (21 %)	85 (77 %)	2 (2 %)
GBP	59 (77 %)	18 (23 %)	0 (0 %)
CAD	23 (33 %)	46 (66 %)	1 (1 %)

Tab. II lists the displayed sides of the coins. Overall, close to one third of coins is shown on the obverse and about two thirds are shown on the reverse. The edge is only rarely the primary focus in the photo - only about 1 %, an example is shown in Fig. 21. Otherwise, there are clearly currency specific preferences to show either the obverse or reverse. Two thirds of USD coins are shown on the obverse, while the overwhelming majority of EUR coins (94 %) is shown on the reverse. Contrary to [2] where the shown side of CNY coins was about fifty-fifty, the presented quantitative analysis suggests that Yuan coins are predominantly shown on the reverse (79 %). Regrettably, this makes the joke about authors deciding the displayed side by coin flip obsolete.

As a consequence, the country of origin of most Euro isn't known as the reverse is the common side that shows a map of Europe. The year of minting is also unknown for most Euros for the same reason. The few Euros, where the obverse is visible, are listed in Tab. III. All nine Greek Euros are in the same article, two Spanish Euros are also in the same article, the other listed coins occur in different articles.

It should be noted that conscious obverse/research choices may carry meaning, although the collected articles don't directly mention the choice process to prefer one side over the other. The obverse typically displays the head of state, state emblem, coat of arms and country name. For Euro coins the common sides are the same among all Euro member states, while the other sides are country specific.

TABLE III
EURO COIN OBVERSE FACES. THE OBVERSE FACES OF 255 EURO COINS (94 % OF EURO COINS) ARE UNKNOWN, BECAUSE THE PHOTOS SHOW THE REVERSE.

Country	Obverse	Count (occ.)	Count (article)
Austria	Edelweiß	1	1
Belgium	Albert II (1st type)	1	1
France	Marianne	1	1
Germany	Bundesadler	3	3
Greece	Rigas Velestinlis-Fereos	9	1
Italy	Dante Alighieri	1	1
Italy	Vitruvian Man	4	4
Spain	Felipe VI	3	2

N. Representations of currencies other than coins are not used

Generally, only coins are used as size reference. I've encountered only one article which uses other representations of currencies. In [83, Fig. 5] a 5 EUR banknote is used and the caption states: *Dimensions of the conductive plates compared to a 5€ banknote.* I haven't stumbled upon any cheques, cash cards or credit cards, bank statements, electronic funds, bonds, gift cards or similar items.

O. No objects similar to coins are used as size reference

The most common methods used to measure size that I've observed while browsing the literature are dimensions, size bars, rulers and measuring tapes. Several other objects of well known size are used as a size reference: pens, matchboxes, paperclips, camera lids, hammers, hands, iPhones, stamps, and many more. However, I haven't found a single other round metal object that is similar to coins: no medals, no lockets, no jewelry, no badges, no tokens, no amulets, no bullion, no blanks.

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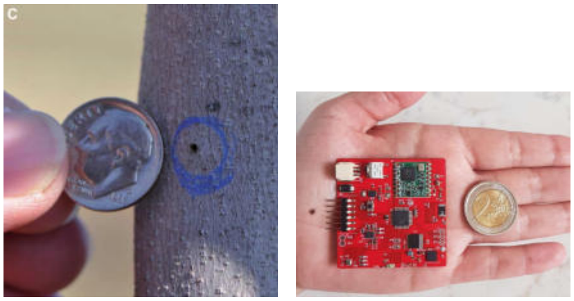


(a) (b)

Fig. 22. a) A coin is held in the scene. The dataset only contains two occurrences where coins are held by fingers, both in [84]. Fig. 4C from [84] is a work of the United States government. Such works are not entitled to domestic copyright protection under U.S. law and are therefore in the public domain. b) Two coins in the dataset lie in the palm of a hand. Fig. 3 from [86], CC-BY 4.0.

Fig. 23. One coin is fixed to both the substrate and the fixture in an upright position, Fig. 3 from [87], CC-BY.

P. Coins are placed flat

How are coins positioned in scenes? The data show that the majority of coins is lying (1636, 92.6 %) followed by coins standing on the edge (57, 3.2 %) and coins leaning (44, 2.5 %). Typically coins lean against an object, but there are also examples of coins leaning on their own which hints at both obscured fixtures that keep coins in a leaned position and that these authors invested extra effort to place coins in leaning positions. 26 coins (1.5 %) are fixed to a wall. All 26 of them are found in [25] in which the authors show photos of a large number of objects and they have prepared a standing wall piece with a coin on it that serves as background for many of the objects. Two coins (both in [84]) are held with fingers. An example is shown in Fig. 22a. Two coins are lying in the palms of hands [85], [86] and they are classified under *lying*. Fig. 22b shows an example of a coin and device lying in the palm of a hand. One coin is soldered to the object itself [80], see Fig. 20. The soldered coin is shown in a horizontal position, but it isn't lying. There is another special case in [87], where the authors have mounted the coin in an upright position to both the substrate and a fixture, see Fig. 23.

Q. Coins are not combined with other measures of size

Coins are not the only measures of size in scientific publications. Sometimes coins share this honor with other measurement methods, which is investigated in this section. Overall 297 occurrences are observed in which other methods are used as size measurement or comparison in the same photo, while 1472 photos only use a single coin. Tab. IV gives the numbers of combinations with coins. Rulers, drawn dimensions and size bars are the most prominent methods used in the searched articles and they are also the most prominent methods used in conjunction with coins. The numbers for same and other currencies are odd, because the three stacked coins in [34] (see Fig. 9a) and because Fig. 11 in [88] uses a 100 KRW, a 1 EUR and a 0.25 USD coin (reproduced in Fig. 24).

TABLE IV
MEASUREMENT DEVICES AND SIZE ESTIMATION TECHNIQUES THAT ARE COMBINED WITH COINS.

ruler	132
dimensions	75
size bar	58
coin (same currency)	9
graph paper	8
coin (other currency)	7
indication of length	5
caliper	5
scale on glass tube	1
interlocking plastic brick board	1

R. Only one coin is used per photo

Tab. IV reveals that not many photos contain more than one coin. Three photos contain two coins of the same currency and one photo three coins of the same currency. As found in Sec. III-C, coins are usually not used as measurement unit (Fig. 9) and they are usually not used as lower and upper bounds for measurement purposes (Sec. III-K and Fig. 19).

It's also not usual to provide several coins in case readers are not familiar with a given foreign currency. Two photos contain two coins from different currencies and one photo contains three coins from three different currencies [88]. The only photo with three coins from different currencies is reproduced in Fig. 24. It seems there are no other incentives for researcher to place more than one coin in the same photo.

Generally the rule can be formulated that when a coin is used as size reference, then one and only one coin is used. Only 16 of the 1769 coins (0.9 %) in the data set are in photos with other coins.

S. If both sides of an object are shown, either the same coin side is displayed in each view, or only one view features a coin

There is a recurring view in technical articles that shows both the top and bottom or the front and back of a device. For 1364 coin images this isn't applicable, as there is only one view of an object. In 167 cases both the front/back or top/bottom of an object are shown, but a coin is only used in one view. Of the remaining 236 cases where two sides of an object are shown and both views contain a coin, 199 times the

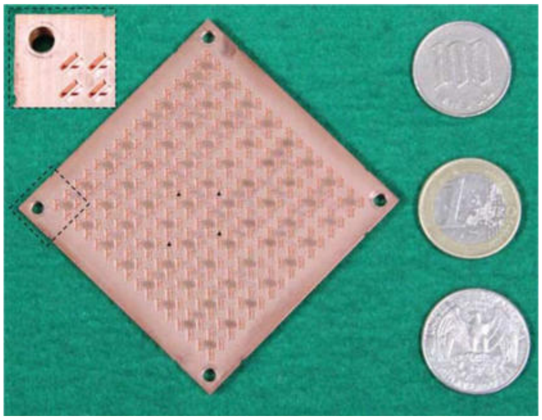


Fig. 24. Tomura *et al.* use three coins from different currencies in one photo: 100 JPY, 1 EUR and 0.25 USD, Fig. 11 from [88], copyright © 2014, IEEE.

displayed side of the coin stays the same, 35 times the shown side of the coin changes with the object view and 2 cases are undecided. Of the 199 coins that stay on one side, 143 show the reverse and 56 show the obverse. [89] is a special case that shows the top and bottom sides of a printed circuit board (PCB). The top view uses a mirrored US quarter and the bottom view uses a regular photo of a quarter. Fig. 25 shows examples.

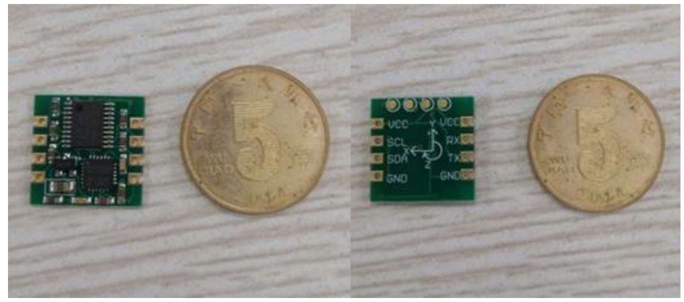
IV. Notable examples, outliers and oddities

[92] is a big rule breaker, but it was excluded from the statistical investigation, because it is more an editorial or summary than an article. The coin in [92] isn't used in a photo, it's only surrounded by sketches. Actually it's not used in a proper figure either, because it's not labeled as such and the short two page text doesn't contain a single properly labeled figure which makes it one of the few articles that contains more coins than figures. It depicts the reverse of a US dime, which is unusual for USD, that is placed behind a sketch, which is also unusual. The coin is referenced directly in the "figure" with the text "Dime for scale". The authors are affiliated with Australia, where AUD is used instead of USD.

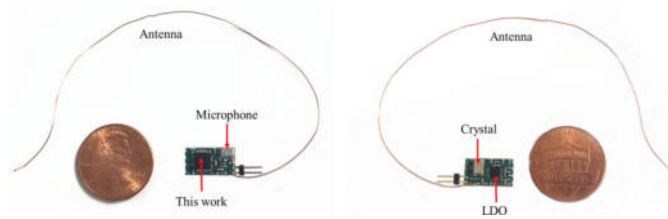
The sample contains a penny with such heavy wear that the zinc is visible through the copper plating, see [93] or Fig. 26.

The robot in [94] is small. So small actually, that in one photo it is compared to the Lincoln Memorial on the reverse of an USD penny and in a second photo it is compared to the size of the Lincoln statue of the same penny. Fig. 27 reproduces the photo. Note how the two Lincoln Memorial pillars provide an upper bound to the robot's size.

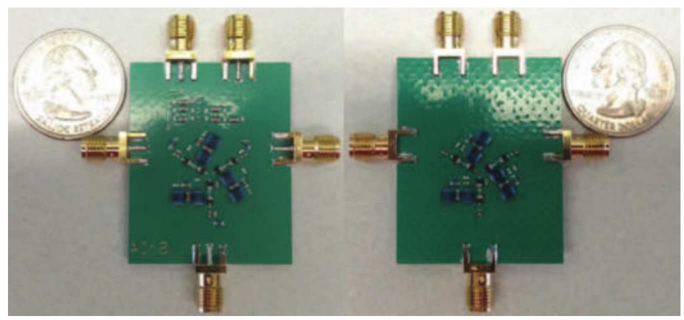
There are several mirrored images of coins in the sample. A mirrored Hong Kong dollar is used in [95]. Two US pennies are used for scale in [96] and both images are mirrored. Mahmoud et al. mirror a Chinese yuan coin [97]. [98] reuses a mirrored US quarter image from another article in which the coin is also mirrored. The top and bottom sides of a PCB are shown in [89]. The top view uses a mirrored US quarter and the bottom view uses a regular photo of a quarter, see Fig. 25c. [99] uses three non-reflected photos of British one pound coins and one mirrored photo in which Elizabeth II



(a)



(b)



(c)

Fig. 25. a) Fig. 2 from [90] shows front and back views of a sensor. The displayed coin side stays the same. Images used with permission, CC-BY 4.0. b) In Figs. 9c and 9d from [91] the displayed side of the coin changes with the view of the device. Used with permission, CC-BY 4.0. c) Kord, Sounas and Alù use a mirrored image of an US quarter as size reference for the top side of their PCB. Figs. 6a and 6b from [89], copyright © 2018 IEEE.

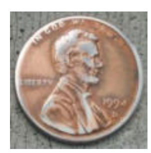


Fig. 26. One US penny in the sample shows such heavy wear that the zinc is visible through the copper plating. Fig. 1b from [93], reused with permission, CC-BY 4.0.

looks to the left. [100] uses a regular and a mirrored two Euro coin. [101] uses two regular US dimes and one mirrored dime.

V. Conclusion

Previous qualitative investigations have engraved depths of insights into our blank understanding of the ways coins exchange size information between author and reader. In this work, we have struck the empirical die to mint a quantitative understanding of coins used for size comparison.

This investigation reveals a prototypical numismatic measurement system that authors use to convey object sizes to readers. Widespread use in the scientific community is now

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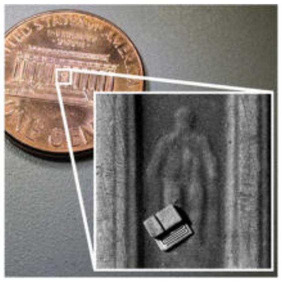

Fig. 27. The size of a robot is compared to the Lincoln statue on a USD penny in Fig. 1 in [94]. Reprinted from [94], with the permission of AIP Publishing.

evident and for several journals the number of articles that use coins as size reference is in the single digit percentage range. The quantitative analysis in this article reveals a consensus is forming on how coins and objects are arranged in scenes. There is consens on some customs such as choosing contemporary circulation coins and only using coins as size reference in photographs. There are currency specific preferences like showing Euro coins predominantly on the reverse and the statistical evaluation shows that authors prefer certain methods over alternatives such as selecting coins from their own currencies and placing coins next to objects.

Our hypothesis is that most authors' simply pick a coin from their wallet. The selection process is never directly mentioned in the found articles, but this analysis provides evidence for this assumption as authors predominantly choose contemporary circulating coins from their own currencies. These are the types of coins that people usually carry on them.

Coins are now much more popular as size reference that other objects with well-known size. Examples of lighters, matchboxes, paperclips, pens, persons, phones, rice grains and stamps used as size reference were found, but only a few articles each. Exact numbers where not gathered during the literature search, but rulers remain the most popular tool to actually measure size in photos, drawn dimensions are the most popular way to show the exact size of an object and size bars are popular to provide a size reference.

Appendix A
The Dataset

The dataset is organized in tabular form and comes with an R script that analyzes the data. The data organization follows the tidy data approach [102]. Each depiction of a coin is an observation and a line in the spreadsheet. There are some asterisks to this as the authors, authors country affiliations, first author affiliations, instances where coins are stated and other measurement devices in the image are comma separated values (CSV). The whole thing should of course be a database, but creating and maintaining database entries for authors and coins would be a tremendously tedious task during data entry and would not provide additional insights (only save a few lines of code during evaluation). Matching authors is an almost impossible task anyway. Initiatives such as ORCID[2] are ongoing in the scientific community, but surnames change, names are abbreviated and affiliations change. Deciding if a Jane Doe and a J. Doe are the same person is tedious work and not worth the effort for this investigation. In its current form data entry is quite easy: You browse the literature until you find a coin used as size reference, go to a new line in the spreadsheet, fill every cell you can and then go back to browsing. I've added some variables (columns) later as it became apparent that certain techniques are more widely applied than initially believed. Other techniques (like mirrored coins or proofs) remain so rare that they are only mentioned in the comments. Additional questions surely sparked my interest while browsing, but are not so interesting that I want to sift through thousand articles again. Linking the articles and coin images directly in the dataset is of course desirable, alas intellectual property laws prevent it. Tab. V provides additional explanation on the spreadsheet column names and some explanation.

Acknowledgment

Currency codes are given in the ISO 4217 standard [103]. Numista.com is a helpful resource to identify coins. The author thanks Markus Greif from the Department of Numismatics and Monetary History at the University of Vienna for the suggestion that choosing to display obverse or reverse might be a conscious statement and for valuable feedback on the manuscript.

Competing Interests

The author frequently exchanges coins for goods and services. Otherwise, there is no conflict of interest.

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TABLE V
SPREADSHEET ENTRIES AND THEIR MEANING

SCI	Is the journal listed in Clarivate's Science Citation Index or Science Citation Index Expanded?
Evaluate	Should the article be evaluated? A *no* excludes the article from further consideration in the computer program.
Reason	The reason why the article is excluded from further consideration
Journal	Title of the conference, journal or book (conference contributions and books from [2] were kept)
Title	Article title
Year	Year of publication
Vol	Volume
No	Issue number
Article_ID	Article ID
Pages	Number of pages excluding title pages, advertising etc.
Figures	Number of figures in the article
Photos	Number of photos in the article
DOI	Digital object identifier
Authors	Author names as listed in article, separated by comma
Authors_Countries	Affiliated countries of all authors, separated by comma
First_Author_Country	Affiliated countries of the first author, separated by comma
Figure	The figure in which the coin is shown
Photograph	Is the coin shown in a photo?
Currency	The coin's currency
Cite	Is the image cited from another publication, reference if yes, otherwise "no"
Edited	Was the image with the coin edited?
Face_Value	The coin's denomination
Standing	Is the coin "standing", "lying", "leaning" or some special case?
Measure_of_Size	Is the coin used as a measure of size?
Unit	Is the coin used as a measurement unit?
Relative_Size	Is the coin "smaller", "larger" or about the "same" size as the object it's compared to?
Lower_Upper_Bound	Are coins used as both lower and upper bound?
Special	Is it a special version of the coin? Examples: bullion coins, national sides of Euro coins, US 50 State Quarter Program
Side	Which side of the coin is predominantly shown (Obverse/Reverse/Edge)?
Year_Issue	Year of coin issue, if visible otherwise empty
Historic	Is a historic coin used? Meaning the coin is no longer legal tender at the time the article was published.
Placement	Where is the coin placed relative to the object? next, in front, on, ...
Stated	Is the use of the coin stated in the article?
Stated_Where	If yes: Where is the use of the coin stated? in figure, caption, text, ...
Stated_Text	If yes: Copy and pasted text that mentions the coin, separated by comma when the coin is mentioned several times
Other_Properties_Used	Are other properties than the coin's size used for measurements? Weight, color, ...
Other_Measure_Photo	Are other measures of size used in same (sub)figure? rulers, size bars, dimensions, ...
Other_Measure_What	If yes: What other measures of size are used? rulers, size bars, dimensions, and so on, separated by comma
View_Changes	Sometimes authors change the shown coin side next to top/bottom views of the object. "n/a": no different views of object, "no": different views, but only one coin, "stays" coin shows the same side in each view, "yes" shown side changes with view
Deduced	Was all information deduced from this depiction of the coin, or where some properties taken from context? yes/no, For example a coin looks like a quarter and the article only contains quarter dollars, then this is likely also a quarter. Many photos are of poor quality and information would be lost if context wasn't considered. If yes: Details are provided as comment.
Comments	Space for comments

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