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APPARATUS FOR PROCESSING RADAR SIGNAL

Abstract

An apparatus for processing radar signals is configured to receive a radar signal that includes a radar frame of a plurality of chirps, where the plurality of chirps includes at least a first group with a first pulse repetition interval, and a second group with a second pulse repetition interval. The groups are separated by a group separation time interval between a final chirp in the first group and a first chirp in the second group, where the group separation time interval is different than one or both of the first pulse repetition interval and the second pulse repetition interval. The apparatus further generates a modified received radar frame by performing a first extrapolation, based on temporal positions of the chirps in the first group of the received radar frame, to generate at least one extrapolated chirp in the modified received radar frame.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. § 119 to Romanian patent application no. A202400057, filed 16 Feb. 2024, the contents of which are incorporated by reference herein.

FIELD

[0002] The present disclosure relates to an apparatus for processing Frequency Modulated Continuous Wave, FMCW, radar signals. In particular, it relates to a system configured to transmit a radar frame and receive the radar frame reflected from one or more targets. It also relates to an associated method.

BACKGROUND

[0003] FMCW radar is commonly used in automotive applications. One of the more challenging issues that affects automotive radar systems is that of real-time velocity disambiguation in the context of time-division-multiplexed, TDM, radar, such as TDM-MIMO. Such a challenge is also applicable to other types of multiplexed radar.

SUMMARY

[0004] According to a first aspect of the present disclosure there is provided an apparatus for processing Frequency Modulated Continuous Wave, FMCW, radar signals, the apparatus configured to: [0005] receive a radar signal comprising a radar frame having reflected from one or more targets, wherein the radar frame comprises a plurality of chirps, the plurality of chirps comprising at least two groups of chirps comprising a first group transmitted with a first pulse repetition interval between the chirps therein, and a second group transmitted with a second pulse repetition interval between the chirps therein, wherein the first group and the second group are separated by a group separation time interval between a final chirp in the first group and a first chirp in the second group that is different than one or both of the first pulse repetition interval and the second pulse repetition interval; [0006] generate a modified received radar frame by at least: [0007] first extrapolation, based on temporal positions of the chirps in the first group of the received radar frame, to generate at least one extrapolated chirp in the modified received radar frame; [0008] perform processing based on said modified received radar frame to determine properties of the one or more targets.

[0009] In one or more examples, the first pulse repetition interval is the same as the second pulse repetition interval.

[0010] In one or more embodiments, said at least one extrapolated chirp generated by the first extrapolation is extrapolated to a time that is later in the received radar frame and between two chirps of the second group in the received radar frame.

[0011] In one or more embodiments, said first extrapolation is configured to generate a plurality of extrapolated chirps which are extrapolated such that the plurality of extrapolated chirps are interleaved with chirps of the second group in the modified received radar frame.

[0012] In one or more embodiments, said generation of the modified received radar frame further comprises a:

[0013] second extrapolation, based on temporal positions of the chirps in the second group of the received radar frame, to generate at least one extrapolated chirp in the modified received radar frame.

[0014] In one or more embodiments, said at least one extrapolated chirp generated by the second extrapolation is extrapolated to a time that is between two chirps of the first group in the modified received radar frame.

[0015] In one or more embodiments, said second extrapolation is configured to generate a plurality of extrapolated chirps which are extrapolated such that the extrapolated chirps are interleaved with

chirps of the first group in the modified received radar frame.
[0016] In one or more embodiments, said generation of the extrapolated chirps is configured to generate the modified received radar frame with a pulse repetition interval less than the first pulse repetition interval and less than the second pulse repetition interval.
[0017] In one or more embodiments, the extrapolation comprises linear extrapolation.
[0018] In one or more embodiments, the apparatus is configured to perform said extrapolation based on Burg's algorithm for autoregressive parameter estimation.
[0019] In one or more embodiments, the generation of the modified received radar frame further comprises the apparatus being configured to: [0020] extract the chirps corresponding to the first group from the received radar frame to generate a first received radar frame; [0021] extract the chirps corresponding to the second group from the received radar frame to generate a second received radar frame; [0022] generate a modified first received radar frame by performing said first extrapolation, based on temporal positions of the chirps in the first group of the first received radar frame, to generate at least one extrapolated chirp at a later time in the modified first received radar frame; [0023] generate a modified second received radar frame by performing second extrapolation, based on temporal positions of the chirps in the second group of the second received radar frame, to generate at least one extrapolated chirp at an earlier time in the modified second received radar frame; [0024] generate a Fast Fourier Transform, FFT, of the modified first received radar frame; [0025] generate a FFT of the modified second received radar frame; and [0026] wherein the modified received radar frame comprises a sum of FFT of the modified first received radar frame and the FFT of the modified second received radar frame.
[0027] In one or more embodiments, the apparatus is configured to: [0028] provide for transmission of the radar frame having said first pulse repetition interval, second pulse repetition interval and said group separation time interval properties.
[0029] In one or more embodiments, the first pulse repetition interval and the second pulse repetition interval each comprise the product of the number of groups, N, and a base time interval, T; and said group separation time interval between any two temporally adjacent groups comprises NT plus or minus T.
[0030] In one or more embodiments, one or both of: [0031] the first extrapolation and any further extrapolation is performed such; and [0032] the group separation time interval and the first pulse repetition interval and the second pulse repetition time interval are selected such; [0033] that the extrapolated chirps are temporally non-overlapping with the chirps of the received radar frame.
[0034] In one or more embodiments, the properties of the one or more targets determined based on the modified received radar frame comprise one or more of: distance to the one or more targets; direction towards the one or more targets; and velocity of the one or more targets.
[0035] According to a second aspect of the disclosure, we provide a method of processing Frequency Modulated Continuous Wave, FMCW, radar signals, the apparatus configured to: [0036] receiving a radar signal comprising a radar frame having reflected from one or more targets, wherein the radar frame comprises a plurality of chirps, the plurality of chirps comprising at least two groups of chirps comprising a first group transmitted with a first pulse repetition interval between the chirps therein, and a second group transmitted with a second pulse repetition interval between the chirps therein, wherein the first group and the second group are separated by a group separation time interval between a final chirp in the first group and a first chirp in the second group that is different than one or both of the first pulse repetition interval and the second pulse repetition interval; [0037] generating a modified received radar frame by: [0038] first extrapolation, based on temporal positions of the chirps in the first group of the received radar frame, to generate at least one extrapolated chirp in the modified received radar frame; and [0039] performing processing based on said modified received radar frame to determine properties of the one or more targets.
[0040] In one or more examples, said first extrapolation is configured to generate a plurality of extrapolated chirps which are extrapolated such that the plurality of extrapolated chirps are at least

partly interleaved with chirps of the second group in the modified received radar frame.
[0041] In one or more examples, said generating of the modified received radar frame further comprises:
[0042] second extrapolation, based on temporal positions of the chirps in the second group of the received radar frame, to generate a plurality of extrapolated chirp in the modified received radar frame.
[0043] In one or more examples, said plurality of extrapolated chirps generated by the second extrapolation are extrapolated such that the plurality of extrapolated chirps are at least partly interleaved with chirps of the first group in the modified received radar frame.
[0044] In one or more examples, one or both of: [0045] the first extrapolation and the second extrapolation is performed such; and [0046] the group separation time interval and the first pulse repetition interval and the second pulse repetition time interval are selected such; [0047] that the extrapolated chirps are temporally non-overlapping with the chirps of the received radar frame.
[0048] While the disclosure is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that other embodiments, beyond the particular embodiments described, are possible as well. All modifications, equivalents, and alternative embodiments falling within the spirit and scope of the appended claims are covered as well.
[0049] The above discussion is not intended to represent every example embodiment or every implementation within the scope of the current or future Claim sets. The figures and Detailed Description that follow also exemplify various example embodiments. Various example embodiments may be more completely understood in consideration of the following Detailed Description in connection with the accompanying Drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0050] One or more embodiments will now be described by way of example only with reference to the accompanying drawings in which:
[0051] FIG. **1** shows an example embodiment comprising a block diagram of an apparatus within a radar system;
[0052] FIG. **2** shows a first example embodiment of a radar frame and the generation of a modified received radar frame that has reflected from one or more objects;
[0053] FIG. **3** shows a second example embodiment of a radar frame and the generation of a modified received radar frame that has reflected from one or more objects;
[0054] FIG. **4** shows a third example embodiment of a radar frame and the generation of a modified received radar frame that has reflected from one or more objects;
[0055] FIG. **5** shows a fourth example embodiment of a radar frame and the generation of a modified received radar frame that has reflected from one or more objects;
[0056] FIG. **6** shows a comparison of example plots of range bins versus doppler bins for received radar frames and modified received radar frames.
DETAILED DESCRIPTION
[0057] We disclose embodiments of an apparatus that provides real-time velocity disambiguation in the context of TDM-MIMO radar, but is also applicable to other types of division multiplexing. As will be familiar to those skilled in the art, for a given wavelength, the maximum unambiguous velocity that can be determined from radar signals depends on the Pulse Repetition Interval, PRI.
[0058] Among many, there are four principal challenges in reducing the PRI: [0059] a) constructing a Voltage Controlled Oscillator (VCO)/Phase Locked Loop (PLL) capable of providing very short chirps for a given bandwidth, [0060] b) constructing a VCO/PLL with extremely fast recovery rate

(hysteresis), c) provision of a processor powerful enough to process the signals and provide Interference Mitigation and range determining fast Fourier transforms between two consecutive chirps, and [0061] d) provision of an Analogue to Digital (ADC) convertor with a sampling rate high enough to enable determination of the desired upper range.

[0062] The example embodiments described transmit a radar frame that is divided into spaced sub-frames or groups each with a predetermined separation between component chirps. It has been found that extrapolation techniques may be applied on the received radar signal such that real and extrapolated samples become interleaved and the PRI is accordingly reduced. A lower PRI allows for a greater maximum unambiguous velocity determination for a target from the radar signals.

[0063] Example FIG. **1** shows a block diagram of an apparatus within a typical radar system **100**. The radar system **100** of the example is of time division multiplexed multiple-input and multiple-output type, TDM-MIMO. It is also of FMCW type. However, the disclosure is not limited to TDM-MIMO radar systems.

[0064] The radar system **100** comprises one or more transmitter arrangements **101** for transmitting the radar signals. The radar signals may be formed of a plurality of radar frames each at a different frequency. The radar frames comprise a plurality of time-spaced chirps. The radar system **100** comprises one or more receiver arrangements **102** for receiving the transmitted radar signals having reflected from one or more targets in an environment. Thus, each receiver arrangement may receive a radar frame of a different frequency and provide it for processing to an apparatus **103**. The apparatus **103** shows, schematically, a series of processing steps that illustrate the processing of the embodiments and will be described later.

[0065] In general, the transmitter arrangement **101** may receive signals **104** from the apparatus **103** to cause it to transmit radar signals which may comprise one or more radar frames. In general, the transmitter arrangement **101** comprises a VCO or PLL **105** that may be controlled to generate radar frames comprising a plurality of chirps and having a particular pulse repetition interval between the chirps. A coupler/splitter **106** is configured to provide part of the signal **107** comprising the generated radar frame to the remainder of the transmitter arrangement **101** and part **108** of the signal comprising the generated radar frame to the receiver arrangement **102**. An amplifier **110** is configured to amplify the part **107** and a phase shifter **111** applies a phase shift to the amplified signal. An antenna **112** provides for transmission of the radar signal to the environment such that it is able to reflect from one or more targets that may be present.

[0066] The receiver arrangement **102** may comprise an antenna **113** to receive the transmitted radar signals and, in particular, the radar frame, having reflected from the one or more targets in the environment. An amplifier **114** amplifies the signal. A mixer **115**, that also receives the part **108**, down-converts the radar signal. A band pass filter **116** or other filter type filters the signal. An analogue to digital converter 117 digitises the signal and provides it to the apparatus **103** for processing. Thus, the apparatus **103** may be configured to receive a (e.g. digital) signal representing the reflected radar frame that was transmitted.

[0067] It will be appreciated that the transmitter arrangement **101** and the receiver arrangement **102** may take other forms and may contain additional or alternative components.

[0068] In general, the apparatus **103** is configured for processing Frequency Modulated Continuous Wave, FMCW, radar signals, which may be received at the input **118** from the receiver arrangement **101**. In some examples, the apparatus **103** may be provided separately from the receiver arrangement **101** and/or the transmitter arrangement **102**. Thus, the functionality of the apparatus **103** may be provided and configured for coupling with the receiver arrangement **101** and/or transmitter arrangement **102**. In the present example, the apparatus **103** includes the functionality to generate the radar frames by way of signals **104** for the transmitter arrangement, but the transmitter arrangement is a separate part. However, in some examples, the apparatus **103** may not provide the signals **104** for generation of the radar frame and this task may be performed by a separate apparatus (not shown). In such an example, the apparatus may be provided with knowledge of the form of the radar frame.

[0069] The apparatus **103** may be configured to pre-process the raw data received from the one or more receiver arrangements at step **120**. Range compression may be performed at step **121**. Steps **122-125** may comprise the advantageous steps performed by the apparatus of the disclosure and will be described in more detail below.

[0070] Constant false alarm rate (CFAR) detection may be optionally performed at step **126**. MIMO array construction may be performed at step **127**. Direction of arrival estimation may be performed at step **128**. Step **128** may include velocity determination.

[0071] It will be appreciated that steps **122-125** may be performed at different times or may be distributed amongst the other processing steps differently in other embodiments.

[0072] An example embodiment will now be described with reference to FIGS. **1** and **2**. FIG. **2** shows a radar frame that has been transmitted by the transmitter arrangement **101**. The radar frame **200** will be modified by its interaction and reflection from the environment. However, for the purposes of describing the present embodiment, the radar frame **200** may also be considered at least representative of what is received by the receiver arrangement **102** having reflected from the one or more targets. The example embodiment provides for advantageous processing of a radar frame having a specific form. Thus, as mentioned above, the apparatus **103** may generate the radar frame as well as process the reflection of it from one or more targets, or, in other examples, may receive information indicative of the radar frame that was transmitted by a different apparatus such that the advantageous processing may be performed.

[0073] In summary, the apparatus is configured to receive, at input **118**, a radar signal representing the reflected radar frame **200**. The radar frame **200**, that was transmitted, comprises a plurality of chirps **201-206**. In the present example, the plurality of chirps of the radar frame are arranged in two groups comprising a first group **201-203** and a second group **204-206**. Each group is shown with three chirps therein for ease of explanation, but in practice there may be many more chirps. In other examples, two or more or three or more groups of chirps may be provided in the radar frame. The chirps of one group relative to another group and/or the chirps within a group may be of the same form (i.e. change in frequency over time) or different. However, the first group of chirps **201-203** are transmitted with a first pulse repetition interval **207** between the chirps therein. The second group of chirps **204-206**, in the present example, are transmitted also with the first pulse repetition interval **207** between the chirps therein (although in other examples the PRI may be different). The first group **201-203** and the second group **204-206** are separated by a group separation time interval **208** between a final chirp **203** in the first group **201-203** and a first chirp **204** in the second group **204-206** that is different than the first pulse repetition interval **207**. In one or more examples, the group separation time interval **208** is different than the first pulse repetition interval **207** by one chirp duration **209** or at least one chirp duration **209**.

[0074] In some examples, the group separation time interval **208** is greater than the first pulse repetition interval **207** by at least one chirp duration **209**. In some examples, the group separation time interval **208** is less than the first pulse repetition interval **207** by at least one chirp duration.

[0075] In the present example, the first pulse repetition interval **207** comprises 2T. The group separation time interval **208** comprises 3T. Thus, in the present example, the first pulse repetition interval **207** comprises twice a base time interval, T, while the group separation time interval **208** is greater, such as by at least one base time interval T, and in some examples comprises an odd integer multiple of the base time interval, T.

[0076] In other examples, the first pulse repetition interval **207** comprises NT where N is the number of groups of chirps and T is a predetermined base time interval. The group separation time interval **208** is different than the first pulse repetition interval **207** by at least one chirp duration.

[0077] In a further example, the first pulse repetition interval **207** comprises between 2T and 4T.

[0078] The apparatus **103** is configured to generate a modified received radar frame **210** based on the received radar frame **200** by performing the following steps. The apparatus **103** may comprise a processor and memory or other processing circuitry for performing the generation of the modified received radar frame **210**.

[0079] The apparatus **103** is configured to perform a first extrapolation **211**, based on temporal positions of the chirps **201-203** in the first group of the received radar frame, to generate at least one extrapolated chirp **212** at a later time in the modified received radar frame **210**.

[0080] The first extrapolation **211** may comprise determining the time spacing between the chirps **201-203** of the first group and, by linear extrapolation, determine a time at which the at least one extrapolated chirp **212** would be received had it been transmitted in the radar frame **200**.

[0081] The group separation time interval **208** and the first pulse repetition interval **207** are determined such that the one or more extrapolated chirps **212** do not temporally overlap with the plurality of chirps **201-206** in the modified received radar frame **210**.

[0082] The apparatus **103** is configured to perform processing based on said modified received radar frame **210** to determine properties of one or more targets. The properties that may be determined may be those that are conventionally determined with processing of FMCW radar frames and will be familiar to those skilled in the art. For example, determining the presence or quantity of one or more targets, determining the range to the one or more targets, determining the direction to the one or more targets, and/or determining the velocity of the one or more targets.

[0083] Example FIG. **3** shows a further example of generation of the modified received radar frame **302**. In this example, the modified received radar frame **302** is generated by the first extrapolation **311**, the result shown as **300**, and a second extrapolation **312**, the result shown as **301**, to form the final modified received radar frame **302**. However, it will be appreciated that in other embodiments, the modified received radar frame may comprise the frames shown as **300** or **301** with only part of the extrapolation performed.

[0084] In the example (part) modified received radar frame **300**, the first extrapolation **311** is again based on temporal positions of the chirps **201-203** in the first group of the received radar frame **200**. In this example, the first extrapolation is configured to generate a plurality of extrapolated chirps **212**, **213**, **214** each at a different later time in the modified received radar frame **210**.

[0085] In this example, at least one of the extrapolated chirps generated by the first extrapolation **311** are extrapolated to a time that is between two chirps of the second group in the received radar frame. Thus, extrapolated chirp **213** is between chirps **204** and **205**. Likewise, extrapolated chirp **214** is between chirps **205** and **206**.

[0086] Further, in this example, the first extrapolation **311** is configured to generate a plurality of extrapolated chirps **212**, **213**, **214** which are extrapolated such that the extrapolated chirps **212**, **213**, **214** are interleaved with chirps **204-206** of the second group in the (part) modified received radar frame **300**. Further, in this or other examples, at least one extrapolated chirp **212** may be extrapolated to a time temporally (directly) adjacent to a first chirp **204** of the second group **204-206**.

[0087] The generation of the modified received radar frame **301** comprises a second extrapolation **312**, based on temporal positions of the chirps in the second group **204-206** of the received radar frame, to generate at least one extrapolated chirp **215**, **216**, **217** at an earlier time in the (part) modified received radar frame **301**. In the present example a plurality of extrapolated chirps **215**, **216**, **217** each at a different earlier time are generated.

[0088] In this example, at least one of the extrapolated chirps **215**, **216**, **217** generated by the second extrapolation **312** are extrapolated to a time that is between two chirps of the first group **201-203** in the received radar frame. Thus, the extrapolated chirp **215** is between chirps **201** and **202**. Likewise, the extrapolated chirp **216** is between chirps **202** and **203**.

[0089] Further, in this example, the second extrapolation **312** is configured to generate a plurality of extrapolated chirps **215**, **216**, **217** which are extrapolated such that the extrapolated chirps **215**, **216**, **217** are interleaved with chirps **201-203** of the first group in the modified received radar frame **301**. Further, in this or other examples, at least one extrapolated chirp **217** may be extrapolated to a

time temporally (directly) adjacent to a final chirp **203** of the first group **201-203**.
[0090] Finally, the modified received radar frame **302** is generated based on a combination of the result of the first extrapolation **311** and the result of the second extrapolation **312**.
[0091] The modified received radar frame **302** has a pulse repetition interval **303** of base time interval, T, which is less than the first pulse repetition interval, 2T. At least velocity determination of the one or more targets may be performed on one or more such generated modified received radar frames **302**. The reduced pulse repetition interval **303** "T" created by the interpolation of real chirps in the different groups has been found to provide for more effective unambiguous velocity determination of one or more targets.
[0092] Thus, to summarize, the radar frame **200** is generated with at least two groups of chirps having at least a first pulse repetition interval and a group separation time interval **208**, and based on extrapolation of the chirps of at least a subset of the groups, the pulse repetition interval of at least a part of the modified received radar frame **302** generated by the extrapolation is less than the first pulse repetition interval. Further, the extrapolation that is performed and/or the group separation time interval **208** and the first pulse repetition interval **207** is selected such that the extrapolated chirps are temporally non-overlapping with the chirps of the received radar frame **200**.
[0093] FIG. **4** shows a further embodiment that includes separating the first group and the second group in the received radar frame, and performing the first extrapolation and the second extrapolation on the separated parts before recombining the parts. In the present example, a Fast Fourier Transform is applied before their recombination.
[0094] Thus, with reference to FIG. **4**, the apparatus **100** may be configured to: [0095] extract the chirps **201-203** corresponding to the first group from the received radar frame **200** to generate a first received radar frame; [0096] extract the chirps **204-206** corresponding to the second group from the received radar frame **200** to generate a second received radar frame; [0097] generate a modified first received radar frame **401** by performing said first extrapolation, based on temporal positions of the chirps in the first group of the first received radar frame **401**, to generate a plurality of extrapolated chirps **412-415** at a later time in the modified first received radar frame; and [0098] generate a modified second received radar frame **402** by performing the second extrapolation, based on temporal positions of the chirps in the second group of the second received radar frame **402**, to generate a plurality of extrapolated chirps **416-418** at an earlier time in the modified second received radar frame **402**.
[0099] The apparatus **103** is configured to determine an FFT of the modified first received radar frame **401**. Further, the apparatus **103** is configured to determine an FFT of the modified second received radar frame **402**.
[0100] Thus, in this example, the modified received radar frame **420** comprises a sum of the FFT of the modified first received radar frame and the FFT of the modified second received radar frame.
[0101] We now return to steps **122-125** shown in the apparatus **103**. The steps comprise, at step **122**, perform the first extrapolation and however many further extrapolations, such as the second extrapolation, to realise interleaved, modified received radar frames (also known as "Doppler samples"). This may be performed for each frequency at which the radar system **100** operates.
[0102] Step **123** represents the computing of the FFT of the first/second/etcetera modified received radar frame for each group separately.
[0103] Step **124** represents constructing the modified received radar frame **420**, otherwise termed the "Doppler profile" by summing the FFT results of each group determined in step **123**.
[0104] Step **125** represents performing a level check, which will be described in more detail below.
[0105] It will be appreciated that the steps **122-124** are a brief summary of the method disclosed herein. In more detail, steps **122-124** may comprise the apparatus being configured to: [0106] 1) Provide for transmission of a radar frame having M groups of chirps with MT spacing within each group, where M is even, and the group separation time interval is an odd number of T between groups. [0107] 2) Perform range processing as will be known to those skilled in the art is

performed. [0108] 3) The following steps are performed for each range bin: [0109] a. Separate slow-time samples into groups based on PRI spacing as exemplified in FIG. **4**; [0110] b. Use extrapolation, which may include prediction techniques, to increase a length of each group (in terms of the number of chirps, including real chirps+extrapolated chirps) such that after super positioning all of the extrapolated groups, a full or almost full frame is obtained (i.e. slow-time samples (chirps) are uniformly spaced at **7**); [0111] c. Perform the Doppler FFT as described with reference to FIG. **4**; [0112] 4) The apparatus is configured to generate a range-doppler map based on the resultant modified received radar frames for subsequent, conventional processing.

[0113] The extrapolation performed in step **3** may include the Burg Method, Yule Walker Equations, or Levinson Method to estimate an Autoregressive model based on a given order. Thus, as will be understood by those skilled in the art, prediction coefficients from the AR model and existing samples (chirps) in each group are used to extrapolate the number of chirps. A second possible method for extrapolating may be use of an Adaptive Filter or Neural Network (RLS, LMS, etc) as a linear predictor to predict future/past samples. Other methods are possible, and it will be appreciated that the embodiments of the present disclosure relate to the extrapolation of chirps in the groups as described herein to improve the PRI rather than the precise method by which the extrapolation is performed.

[0114] Before describing the level check process, FIG. **5** illustrates an embodiment in which the transmitted and received radar frame **500** comprises four groups of chirps, namely a first group **501**, a second group **502**, a third group **503** and a fourth group **504**.

[0115] In a first extrapolation, the first group is extrapolated (only) to a later time to provide the extrapolated chirps **510**, **511**, **512**.

[0116] In a second extrapolation, the second group is extrapolated to earlier and later times to provide the extrapolated chirps **520**, **521**, **522**, **523**, **524**.

[0117] In a third extrapolation, the third group is extrapolated to earlier and later times to provide the extrapolated chirps **530**, **531**, **532**, **533**.

[0118] In a fourth extrapolation, the fourth group is extrapolated (only) to earlier times to provide the extrapolated chirps **540**, **541**.

[0119] The resulting modified received radar frame is shown as **550**. Thus, the number of extrapolated chirps extrapolated from a particular group may be independent of any other group. Further, the chirps of each group may be extrapolated to earlier and/or later times in the received radar frame **500** when generating the modified received radar frame **550**. In particular, for a radar frame comprising three or more groups, a group located in the radar frame with other groups earlier and later may be extrapolated to earlier and later times, while those groups at the beginning and end of the radar frame may be extrapolated only in one temporal direction.

[0120] We will now describe the optional level check step **125** with reference to FIG. **6**.

[0121] FIG. **6** shows a series of plots of range bins vs doppler bins, as will be familiar to those skilled in the art.

[0122] Plot **601** shows the plot of the FFT of the first group. Plot **602** shows the plot of the FFT of the second group. Plot **603** shows the sum of the FFT of the first group and the FFT of the second group. It can be seen that due to slight phase errors caused by the generation of the modified received radar frame, an ambiguity remains represented by the two regions **604** and **605** rather than a single region.

[0123] This ambiguity can be removed as shown in plot **606**, by simply crosschecking the level of k*FFT {G**1**+G**2**}≤FFT {G**1**}+FFT {G**2**}, where k is a constant close to "1"; and G**1** are the samples representing the chirps of the first group, e.g. **201-203**, **212-214** and G**2** are the samples representing the chirps of the second group, e.g. **204-206**, **215-217** in the slow time domain.

[0124] With this level check performed, it can be seen that plot **606** includes only one region **607** and thereby the ambiguity is resolved. Thus, samples where k*FFT {G**1**+G**2**}≤ FFT {G**1**}+FFT {G**2**} are removed. Thus, the apparatus may be configured to, in processing and generating the modified received radar frame(s), evaluate which samples representing the chirps of the radar frame meet the condition k*FFT {G**1**+G**2**}≤FFT {G**1**}+FFT {G**2**} and remove them in the modified received radar frame.

[0125] Implementation-wise, the apparatus is configured to apply the techniques described herein per iso-range line or per range bin. As will be understood, if you have a Range-Doppler Map, an iso-range line or range-bin can be a horizontal line containing all the Doppler bins at that particular range. In one or more examples, the techniques described herein may be applied selectively.

[0126] In one or more examples, the extrapolation may be based on an autoregressive (AR) parameter estimation technique in which the AR prediction coefficients are the same for all of the groups **201**, **202**, **501**, **502**, **503**, **504**, meaning that either they may only be computed once, or averaged for a more robust performance. This statement also holds for the multiple RX and TX, meaning that for a 3TX-4RX TDM MIMO radar, only one set of coefficients is needed for all channels.

[0127] In one or more examples, the level check step **125** may replace the CFAR step **126**.

[0128] The extrapolations described herein may take various forms. In one or more examples, the extrapolation performed is a linear extrapolation. In one or more other examples, the extrapolation is based on Burg's algorithm for autoregressive parameter estimation.

Burg's Algorithm

Example Algorithm: Burg Recursion

TABLE-US-00001 Input: x, p, N Output: A.sub.k Initialize: f.sub.0 = b.sub.0 = x, A.sub.0 = 1 for k = 0: p − 1 for n = 0: N − 1 − k μ.sub.k(f.sub.k(n), b.sub.k(n)) f.sub.k+1(n) = f.sub.k(n) + μ.sub.k * b.sub.k(n) b.sub.k+1(n) = b.sub.k(n) + μ.sub.k * f.sub.k(n) end A.sub.k+1 = [A.sub.k; 0] + μ.sub.k * [0; flip(A.sub.k)] End

[0129] Where x is the input signal to the algorithm, where p is the order or number of poles that describe the Auto Regressive model, N is the number of samples in x, Ak are the prediction coefficients, and the vectors f0, b0, fk, and bk are intermediary results in the algorithm. ηk is the prediction step.

[0130] Burg's algorithm for AR parameter estimation allows extrapolation of the input signal, which helps increasing spectral resolution. Being most popular for minimizing both forward and backward prediction errors, Burg's algorithm can be viewed as a constrained least squares minimization.

[0131] The assumption made for this algorithm is that the process is wide sense stationary, hence the coefficients of the backward prediction error are identical to the coefficients of the optimum forward prediction error, but conjugated and reversed in time. As result the forward linear prediction error, ƒ.sub.e(n) is defined for p≤n≤N−1, where a.sub.p0 is defined as unity and a.sub.pk are the AR coefficients at order p, and x.sub.n are the data samples.

[00001] $f_e(n) = x_n - \hat{x}_n = \underset{k=0}{\overset{p}{.\mathrm{Math}.}}\ a_{\mathrm{pk}} x_{n-k}$

[0132] Backward linear prediction error is defined for p≤n≤N−1, too and is defined as:

[00002] $b_e(n) = x_n - \hat{x}_n = \underset{k=0}{\overset{p}{.\mathrm{Math}.}}\ a^*_{\mathrm{pk}} x_{n-p-k}$

where the asterisk means the complex conjugate operation. To estimate the AR model coefficients, each a.sub.pk coefficient must satisfy Levinson recursion:

[00003] $a_{k+1}(i) = a_k(i) + \quad a^*_k(k-i+1)$

where i= [1, k] and μ is the constrained coefficient.

[0133] This constraint ensures filter is stable, which means all the poles are positioned within the unit circle. Burg changed the way μ is computed, by minimizing the total sum of ƒ.sub.e(n) and b.sub.e(n).

[0134] The above pseudocode snapshot shows that μ is updated for each k. This was possible based on the forward linear prediction:

$f(n)=\hat{x}_n=-\sum_{k=1}^{p} a_{pk} x_{n-k}$

and backward linear prediction:

$b(n)=\hat{x}_n=-\sum_{k-1}^{p} a_{pk} x_{n+k}$

equations written in a recursive manner based on the Levinson recursion.

[0135] After μ was updated, AR model parameters a_{pk} are updated in the last line. Burg's algorithm shows a computation complexity that requires $3Np-p^2-N+3p$ complex multiplications, $3Np-p^2-2N-p$ complex adds, and p real divisions. Moreover, storage of $3N+p+2$ complex values is also required.

[0136] The instructions and/or flowchart steps in the above figures can be executed in any order, unless a specific order is explicitly stated. Also, those skilled in the art will recognize that while one example set of instructions/method has been discussed, the material in this specification can be combined in a variety of ways to yield other examples as well, and are to be understood within a context provided by this detailed description.

[0137] In some example embodiments the set of instructions/method steps described above are implemented as functional and software instructions embodied as a set of executable instructions which are effected on a computer or machine which is programmed with and controlled by said executable instructions. Such instructions are loaded for execution on a processor (such as one or more CPUs). The term processor includes microprocessors, microcontrollers, processor modules or subsystems (including one or more microprocessors or microcontrollers), or other control or computing devices. A processor can refer to a single component or to plural components.

[0138] In other examples, the set of instructions/methods illustrated herein and data and instructions associated therewith are stored in respective storage devices, which are implemented as one or more non-transient machine or computer-readable or computer-usable storage media or mediums. Such computer-readable or computer usable storage medium or media is (are) considered to be part of an article (or article of manufacture). An article or article of manufacture can refer to any manufactured single component or multiple components. The non-transient machine or computer usable media or mediums as defined herein excludes signals, but such media or mediums may be capable of receiving and processing information from signals and/or other transient mediums.

[0139] Example embodiments of the material discussed in this specification can be implemented in whole or in part through network, computer, or data based devices and/or services. These may include cloud, internet, intranet, mobile, desktop, processor, look-up table, microcontroller, consumer equipment, infrastructure, or other enabling devices and services. As may be used herein and in the claims, the following non-exclusive definitions are provided.

[0140] In one example, one or more instructions or steps discussed herein are automated. The terms automated or automatically (and like variations thereof) mean controlled operation of an apparatus, system, and/or process using computers and/or mechanical/electrical devices without the necessity of human intervention, observation, effort and/or decision.

[0141] It will be appreciated that any components said to be coupled may be coupled or connected either directly or indirectly. In the case of indirect coupling, additional components may be located between the two components that are said to be coupled.

[0142] In this specification, example embodiments have been presented in terms of a selected set of details. However, a person of ordinary skill in the art would understand that many other example embodiments may be practiced which include a different selected set of these details. It is intended that the following claims cover all possible example embodiments.

Claims

1-15. (canceled)
16. A processing apparatus of a radar system, the processing apparatus comprising: an input configured to receive a Frequency Modulated Continuous Wave, FMCW, radar signal representing a received radar frame that has reflected from one or more targets, wherein the received radar frame includes a plurality of chirps, the plurality of chirps including at least two groups of chirps comprising a first group of chirps with a first pulse repetition interval between the chirps in the first group of chirps, and a second group of chirps with a second pulse repetition interval between the chirps in the second group of chirps, wherein the first group and the second group are separated by a group separation time interval between a final chirp in the first group and a first chirp in the second group, wherein the group separation time interval is different than one or both of the first pulse repetition interval and the second pulse repetition interval; and processing circuitry coupled to the input, wherein the processing circuitry is configured to generate a modified received radar frame by performing a first extrapolation, based on temporal positions of the chirps in the first group of the received radar frame, to generate at least one extrapolated chirp in the modified received radar frame, and process the modified received radar frame to determine properties of the one or more targets.
17. The processing apparatus of claim 16, wherein the at least one extrapolated chirp generated by the first extrapolation is extrapolated to a time that is after the first group in the received radar frame.
18. The processing apparatus of claim 16, wherein the first extrapolation is configured to generate a plurality of extrapolated chirps which are extrapolated such that the plurality of extrapolated chirps are interleaved with chirps of the second group in the modified received radar frame.
19. The processing apparatus of claim 16, wherein the processing circuitry is configured to generate the modified received radar frame by: performing a second extrapolation in addition to performing the first extrapolation, wherein performing the second extrapolation is based on temporal positions of the chirps in the second group of the received radar frame, to generate at least one extrapolated chirp in the modified received radar frame.
20. The processing apparatus of claim 19, wherein the at least one extrapolated chirp generated by the second extrapolation is extrapolated to a time that is before the second group in the received radar frame.
21. The processing apparatus of claim 19, wherein the second extrapolation is configured to generate a plurality of extrapolated chirps which are extrapolated such that the extrapolated chirps are interleaved with chirps of the first group in the modified received radar frame.
22. The processing apparatus of claim 16, wherein the processing circuitry is configured to generate the modified received radar frame with a third pulse repetition interval less than the first pulse repetition interval and less than the second pulse repetition interval.
23. The processing apparatus of claim 16, wherein the first extrapolation comprises linear extrapolation.
24. The processing apparatus of claim 16, wherein the processing apparatus is configured to perform the first extrapolation based on Burg's algorithm for autoregressive parameter estimation.
25. The processing apparatus of claim 16, wherein the processing apparatus is further configured to: extract the chirps in the first group of chirps from the received radar frame to generate a first received radar frame; extract the chirps in the second group of chirps from the received radar frame to generate a second received radar frame; generate a modified first received radar frame by performing the first extrapolation, based on temporal positions of the chirps in the first group of the first received radar frame, to generate at least one extrapolated chirp at a time that is after the first group in the modified first received radar frame; generate a modified second received radar frame by performing a second extrapolation, based on temporal positions of the chirps in the second group of the second received radar frame, to generate at least one extrapolated chirp at a time that

is before the second group in the modified second received radar frame; generate a Fast Fourier Transform, FFT, of the modified first received radar frame; generate a FFT of the modified second received radar frame; and wherein the modified received radar frame comprises a sum of the FFT of the modified first received radar frame and the FFT of the modified second received radar frame.

26. The processing apparatus of claim 16, wherein the processing apparatus is further configured to: provide for transmission of the FMCW radar signal having the first group of chirps with the first pulse repetition interval and the second group of chirps with the second pulse repetition interval.

27. The processing apparatus of claim 26, wherein: the first pulse repetition interval and the second pulse repetition interval each comprise the product of a number of groups, N, and a base time interval, T; and the group separation time interval between any two temporally adjacent groups of chirps comprises NT plus or minus T.

28. The processing apparatus of claim 26, wherein: the extrapolated chirps are temporally non-overlapping with the chirps of the received radar frame.

29. The processing apparatus of claim 16, wherein the properties of the one or more targets determined based on the modified received radar frame consist of one or more properties selected from a distance to a target; a direction towards a target; and a velocity of a target.

30. The processing apparatus of claim 16, wherein the first pulse repetition interval is the same as the second pulse repetition interval.

31. A method of processing radar signals, the method comprising: receiving, by an input, a Frequency Modulated Continuous Wave, FMCW, radar signal representing a received radar frame that has reflected from one or more targets, wherein the received radar frame includes a plurality of chirps, the plurality of chirps including at least two groups of chirps comprising a first group of chirps with a first pulse repetition interval between the chirps in the first group of chirps, and a second group of chirps with a second pulse repetition interval between the chirps in the second group of chirps, wherein the first group and the second group are separated by a group separation time interval between a final chirp in the first group and a first chirp in the second group, wherein the group separation time interval is different than one or both of the first pulse repetition interval and the second pulse repetition interval; generating, by processing circuitry, a modified received radar frame by performing a first extrapolation, based on temporal positions of the chirps in the first group of the received radar frame, to generate at least one extrapolated chirp in the modified received radar frame; and processing, by the processing circuitry, the modified received radar frame to determine properties of the one or more targets.

32. The method of claim 31, wherein the first extrapolation is configured to generate a plurality of extrapolated chirps which are extrapolated such that the plurality of extrapolated chirps are at least partly interleaved with chirps of the second group in the modified received radar frame.

33. The method of claim 31, wherein generating the modified received radar frame further comprises: performing a second extrapolation, based on temporal positions of the chirps in the second group of the received radar frame, to generate a plurality of extrapolated chirps in the modified received radar frame.

34. The method of claim 33, wherein the plurality of extrapolated chirps generated by the second extrapolation are extrapolated such that the plurality of extrapolated chirps are at least partly interleaved with chirps of the first group in the modified received radar frame.

35. The method of claim 31, wherein generating of the modified received radar frame further comprises: performing a second extrapolation, based on temporal positions of the chirps in the second group of the received radar frame, to generate a plurality of extrapolated chirps in the modified received radar frame, and wherein the extrapolated chirps are temporally non-overlapping with the chirps of the received radar frame.